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NASA-CR-183906

# Tethered Satellite System Dynamics and Control Review Panel Final Report for Phases 1 & 2



Sponsored by:

GEORGE C. MARSHALL SPACE FLIGHT CENTER
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Under:

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# Tethered Satellite System
# Dynamics and Control Review Panel
# Final Report For Phases 1 & 2

## 1. INTRODUCTION

The Tethered Satellite System (TSS) Dynamics and Control Review Panel (DCRP), also called the "Blue Ribbon Panel" was established in early 1987. Its purpose was to conduct a thorough and independent review of the performance, dynamics, control and mission safety aspects of flying the TSS onboard the Shuttle. This purpose was to be accomplished through completion of three tasks:

1. Review/assess TSS dynamics and control work being performed by the prime contractor and other organizations supporting the TSS analysis effort;
2. Report on the adequacy and completeness of the present ongoing effort;
3. Report findings concerning the need for additional modeling, simulation, ground/space experimentation and/or theoretical work in the field of dynamics and control.

These tasks were to be performed by planning and conducting a series of panel meetings. These meetings would bring together the TSS Project engineers, the analysis groups and the design groups to overview the project and to describe the ongoing activities of each group. After completion of the meetings the panel members would provide comments to the panel chairman who would report findings to the TSS Project

Manager and other cognizant MSFC Officials including the MSFC center director.

## 2. PANEL MEMBERS

The members of the panel were selected from well known experts in dynamics, control and space systems including university faculty, industrial leaders and a former astronaut. These people had no previous connection to the tethered satellite project or related activities. They had years of experience in the aerospace field and could be objective in their assessment of the state of the TSS project. Five persons were selected to serve on the panel under Dr. H. Eugene Worley of Control Dynamics Company (CDy) who would serve as the chairman. The members of the panel are listed below:

1. Dr. Owen Garriott, independent operations consultant (former astronaut, now a Vice President with Teledyne-Brown Engineering);

2. Dr. Leonard Meirovitch, Virginia Polytechnic Institute and State University;

3. Dr. Jerrell R. Mitchell, Ohio University;

4. Dr. Daniel DeBra, Stanford University;

5. Mr. Gilbert L. Roth, Safety, NASA Headquarters.

## 3. PANEL MEETINGS AND ACTIVITIES

The first meeting of the DCRP was held on March 20, 1987 at CDy. The agenda of the meeting is included as appendix A of this report. Several presentations were made to the panel:

1. Introduction and Charge to the Panel -- Chairman;
2. Orientation to TSS Project -- MSFC;
3. Dynamics Working Group Introductions -- MSFC;
4. Dynamics and Control -- MMDA;
5. Dynamics and Control -- SAO;
6. Dynamics and Control -- JSC;
7. Dynamics and Control -- MSFC.

These presentations were made by personnel from CDy, Martin Marietta Denver Aerospace (MMDA), Smithsonian Astrophysical Observatory (SAO), Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC). A speaker was scheduled from Aeritalia/Piano Spaziale Nazionale (AIT/PSN) but was unable to attend.

Thirty five people attended the first panel meeting. They came primarily from the organizations listed above. The list of meeting attendees is included as appendix B.

Minutes of the first meeting are included as appendix C.

The second meeting of the DCRP was held on June 24 and 25 at CDy. The agenda of this meeting is contained in this report in appendix D. The presentations made to the panel are listed below:

1. Introduction and Review of Charge to Panel Members;
2. Description of TSS Satellite Design -- PSN/AIT;
3. Simulation/Validation Focus -- MSFC;
4. TSS Simulation/modeling Status -- MSFC;
5. TSS Dynamics and Control Simulaton Studies -- SAO;
6. Shuttle Engineering Simulation -- JSC;
7. TSS Program Requirements/Objectives -- MMDA;
8. Baseline Mission Profile -- MMDA;
9. TSS Control System Description -- MMDA;
10. Description of Simulation/Analysis Tools -- MMDA;

11. Simulation/Analysis Results -- MMDA;
12. Review of Key Issues from Previous Meeting.

Thirty six people attended the second panel meeting. The list of attendees is provided in Appendix E.

The first two panel meetings are reviewed and summarized in the presentation viewgraphs contained in appendix F. This presentation was given to the MSFC TSS Project office on July 7, 1987. Weaknesses were pointed out in Operations, System, Subsatellite. The panel was then tasked to develop recommendations on what needs to be done to put the TSS Dynamics and Controls "house" in order.

In addition to the panel meetings, several other activities contributed to the findings of the panel. The panel chairman Dr. H. Eugene Worley and panel member Dr. Jerrell .R. Mitchel, an expert in aerospace control systems, traveled to the MMDA facilities at Denver, Co to discuss in greater detail the TSS control system design and to review the TSS hardware test facilities. Additional presentations were made to TSS Project and MSFC Center management. A status review was given to the TSS Project people on September 1, 1987. This review addressed the panel formation, makeup and previous activities. A copy of this status review is provided in Appendix G.

A second review of panel activities was presented to the Deputy TSS Project Manager in preparation for travel by the panel chairman to Venice, Italy to attend the Second International Conference on Tethers in Space in early October 1987. This served as the dry run of a briefing to be given to AIT/PSN. The briefing charts are included as appendix H. After the conference Dr. Worley traveled to Turin to the Aeritalia plant where the TSS1 satellite is being built. There he briefed the Italians on the work of the panel and was briefed in return on satellite status.

## 4. CHRONOLOGY OF EVENTS

The activities of the Tethered Satellite System Dynamics and Control Review Panel including those leading up to its formation are summarized in the following chronology:

1986 Panel activities

| | |
|---|---|
| Pre-panel Contract Discussions | 11- 5-86 |
| Panel Members Selected | 11-18-86 |

1987 Panel activities

| | |
|---|---|
| First Panel Contract Initiated | 2- 2-87 |
| Planning for First Panel Meeting | 3-10-87 |
| First Panel Meeting | 3-20-87 |
| Presention of Results of First Panel Meeting (Viewgraphs in appendix G) | 3-31-87 |
| Plan second panel meeting | 6- 3-87 |
| Visit to MMDA facilities, Denver, Co | |
| Conduct second panel meeting | 6-24-87 |
| Second panel meeting report | 7-27-87 |
| Presentation of 2nd panel mtg results (Viewgraphs in appendix H) | |
| DCRP Review | 9- 1-87 |
| Venice Tether Conference | 4 - 8 Oct 1987 |
| Visit to Aeritalia facility by Panel Chairman | 10-12-87 |
| DCRP Presentation to Aeritalia | 10-12-87 |
| Final Presentation and Recommendations (Viewgraphs in appendix K) | 11-23-87 |

## 5. PANEL CONTINUATION ACTIVITIES

After completion of the original panel activities, additional tasks were assigned to Control Dynamics. These tasks continued the spirit of the DCRP panel activity with an

extension into modeling and analysis of specific problem areas of the system. Greater emphasis was to be placed on analysis and closer support of the analytical work being done at the MSFC S&E Directorate. In this phase, limited funding was available to investigate satellite pendulous motion and the so-called skiprope mode. Pendulous motion of the satellite may result from on-orbit disturbances including normal operation of the tether and satellite controllers. As the satellite is reeled in during retrieval, the tension in the tether which results from gravity gradient forces on the satellite decreases. This tension provides the restoring moment on the satellite keeping it in its proper alignment. As the tension decreases, the amplitude of oscillations increase so that potentially, these pendulous oscillations could become excessive in the final stages of retrieval. To study this phenomenon, it was necessary to enhance our tethered satellites simulation program TSSIM by including rigid body dynamics of the end bodies. The existing version treated point end masses. Funding of this stage of work was insufficient to complete this study as other tasks such as the control system review took priority. This study effort will be continued during the next phase of our work.

The chronology of the second phase of our work is detailed below:

1988 Panel activities

| | |
|---|---|
| Initiate second panel contract | 3 -1-88 |
| TSS Dynamics and Control Review at MSFC | 7-26-88 |
| Attend Technical Briefings, TSS Quarterly Rvw | 9 - 10 Aug 88 |

1989 Panel activities

| | |
|---|---|
| Improvements to TSSIM | March 1988 - April 1989 |
| Attend TSS D & C Readiness Review | 27 Feb - 1 Mar 1989 |
| Initiate third panel contract | 5- 1-89 |

## 6. PANEL ACCOMPLISHMENTS AND CONCLUSIONS

The DCRP accomplished several things during its first period of performance. The various dynamics and controls disciplines of the tether program were brought together for the first time and their activities began to be coordinated. Much of the TSS controls "folklore and legend" began to be written down and organized making it more readily available for review. It was not readily apparent how TSS Control System requirements flowed down to affect the actual design of the deployer system dynamics and control components. Much of the control system description existed either in computer code or in the memory of senior MMAG dynamicists. Very little documented traceability existed. Block diagrams depicting the design of the control system began to make an appearance, although reluctantly. A verification/validation process for the primary dynamics simulation tools got underway in earnest. The TSS community began to get its arms around the dynamics and controls problems and verify that solutions were in hand or problem areas were being identified and investigated.

During the second phase of the panel activity additional tasks were begun. MMAG began a redesign of the TSS deployer control system. No additional panel meetings were held or planned. Provisions were made on a contingency basis to reach individual panel members as consultants if need but none were required during the second phase. The tethered satellites simulation program TSSIM in use at Control Dynamics was modified to take additional dynamic effects into account. Rigid body dynamics of the endbodies was added to study satellite pendulous motions. A model of the Earth's magnetic field was also added so that Lorentz forces acting on a tether carrying a current could be studied. This was in preparation for a review of the excitability of the so-called skiprope mode of tether motion. Beside making modifications to the simulation and studies of dynamic response of the system, we also participated

in an extensive TSS dynamics and control review in February/March 1989 at the MMAG facility in Denver. A thorough review of the system was conducted with numerous review item discrepancies (RID's) generated.

The thorough review and organization activity brought about by the panel and panel activities have been a major factor in getting the TSS Project back on track in the dynamics and controls areas. Much work remains to be done and now is not the time to relax. The major test phases remain and need to be followed closely and critically to assure the important features of the system are completely validated. Analytical investigations must continue and be intensified to quantify the problems and develop solutions for such effects as the skiprope mode and satellite pendulous motion. Verification and validation of the analysis tools must continue to have high emphasis. This is especially true in the area of tether dynamics. Several independent simulations of tether dynamics are currently being used to study system behavior. These should be continued and cross compared to investigate tether phenomena.

Finally, serious consideration should be given to planning and conducting a third meeting of the Dynamics and Control Review Panel to evaluate the progress of efforts to date in the thirty or more months since the panel last met. The purpose of this meeting would be to review the current status of flight preparations such as tests and analyses, to make an independent assessment of the adequacy of the ongoing efforts and to provide inputs to the TSS Project management with regard to readiness of the system for flight.

# APPENDIX A

# FIRST PANEL MEETING AGENDA

TSS DYNAMICS AND CONTROL REVIEW PANEL
FRIDAY MARCH 20, 1987
PRELIMINARY AGENDA

| | | |
|---|---|---|
| 8:30 - 8:50 | WELCOME AND NASA OBJECTIVES | NASA MGMT |
| 8:50 - 9:10 | INTRODUCTION AND CHARGE TO PANEL | CHAIRMAN |
| 9:10 - 10:10 | ORIENTATION TO TSS PROJECT | MMDA |
| 10:10 - 10:25 | BREAK | |
| 10:25 - 10:45 | DYNAMICS WORKING GROUP INTRODUCTIONS | DWG CHAIRMAN |
| 10:45 - 12:00 | MMDA DYNAMICS AND CONTROL | MMDA |
| 12:00 - 12:30 | LUNCH | |
| 12:30 - 1:15 | SAO DYNAMICS AND CONTROL | SAO |
| 1:15 - 2:00 | JSC DYNAMICS AND CONTROL | JSC |
| 2:00 - 2:15 | BREAK | |
| 2:15 - 3:00 | MSFC DYNAMICS AND CONTROL | MSFC |
| 3:00 - 3:45 | PSN/AIT DYNAMICS AND CONTROL | PSN/AIT |
| 3:45 - | DISCUSSION - CONCLUDING REMARKS | CHAIRMAN |

AIT - AERITALIA

JSC - JOHNSON SPACE CENTER

MMDA - MARTIN MARIETTA

MSFC - MARSHALL SPACE FLIGHT CENTER

PSN - PIANO SPAZIALE NAZIONALE (NATIONAL SPACE ~~PROGRAM~~ PLAN)

SAO - SMITHSONIAN ASTROPHYSICAL OBSERVATORY

# APPENDIX B

## FIRST PANEL MEETING ATTENDEES LIST

TETHERED SATELLITE SYSTEM / DYNAMICS AND CONTROL REVIEW PANEL
20 MARCH 1987
ATTENDANCE LIST

| NAME | COMPANY/AGENCY | MAILING ADDRESS | TELEPHONE NUMBER |
|---|---|---|---|
| Peter H. Broussard, Jr. | NASA/MSFC | ED-11 | (205)544-1422 |
| Charles C. Hall | NASA/MSFC | ED-13 | (205)544-1450 |
| Robert Linner | NASA/MSFC | EB-44 | (205)544-3833 |
| John M. Livingston | NASA/MSFC | CS-11 | (205)544-0066 |
| John Gattis | NASA/MSFC | FA-31 | (205)544-0163 |
| Leonard Meirovitch | Virginia Polytechnic Institute & State U. | Dept. Of Engineering Science & Mechanics Blacksburg, VA 24061 | (703)961-5146 |
| Jerrel Mitchell | Ohio University | Dept. of Elec. & Computer Engr., Stocker Center, Ohio, U., Athens, OH 45702 | (614)593-1566 |
| Dan DeBra | Stanford University | AA Stanford, CA 94305 | (415)723-3388 |
| Eugene Worley | Control Dynamics Co. | 600 Boulevard S. Suite 304 Huntsville, AL 35802 | (205)882-2650 |
| Sherman M. Seltzer | Control Dynamics Co. | 600 Boulevard S. Suite 304 Huntsville, AL 35802 | (205)882-2650 |
| R. E. Lake | NASA/MSFC | FA-31 MSFC, AL 35812 | (205)544-1956 |

TETHERED SATELLITE SYSTEM / DYNAMICS AND CONTROL REVIEW PANEL
20 MARCH 1987
ATTENDANCE LIST

| NAME | COMPANY/AGENCY | MAILING ADDRESS | TELEPHONE NUMBER |
|---|---|---|---|
| Linda L. Brewster | NASA/MSFC | FA-31<br>MSFC, AL 35812 | (205)544-0169 |
| Jay H. Laue | NASA/MSFC | FA-31<br>MSFC, AL 35812 | (205)544-0158 |
| Donald D. Tomlin | MSFC/ED13 | ED-13<br>MSFC, AL 35812 | (205)544-1465 |
| Sidney P. Saucier | MSFC | FA-01<br>MSFC, AL 35812 | (205)544-0171 |
| John M. Price | NASA/MSFC | FA-31<br>MSFC, AL 35812 | (205)544-1978 |
| W. Bollendonk | MMDA/Denver | P. O. Box 179<br>Denver, CO 80120 | (303)977-0965 |
| F. Brooks Moore | Control Dynamics Co. | 600 Boulevard S. Suite 304<br>Huntsville, AL 35802 | (205)582-2650 |
| H. Flanders | MMDA/Denver | P. O. Box 179/MS-S8071<br>Denver, CO 80120 | (303)977-5951 |
| C. Bodley | MMDA/Denver | P. O. Box 179/MS-S8071<br>Denver, CO 80120 | (303)977-3168 |
| Bill Woodis | MMDA/Denver | P. O. Box 179<br>Denver, CO 80201 | (303)977-3744 |
| Jayson Cowley | MMDA/Denver | P. O. Box 179<br>Denver, CO 80201 | (303)977-3256 |

TETHERED SATELLITE SYSTEM / DYNAMICS AND CONTROL REVIEW PANEL
20 MARCH 1987
ATTENDANCE LIST

| NAME | COMPANY/AGENCY | MAILING ADDRESS | TELEPHONE NUMBER |
|---|---|---|---|
| Zachary J. Galaboff | NASA/MSFC | ED-13 | (205)544-1446 |
| Keith Mowery | NASA/MSFC | ED-13 | (205)544-1444 |
| Mario Rheinfurth | MSFC | ED-01 | (205)544-1416 |
| Claude Nicollier | NASA/JSC | CB | (713)483-2734 |
| Dave Harshman | RSOC/JSC | JSC - RS16C | (713)282-2789 |
| Jack Macpherson | NASA/MSFC | EJ-61<br>MSFC, AL 35812 | (205)544-6626 |
| Gary Graybeal | NASA/JSC | Code TC2<br>Johnson Space Center<br>NASA, Houston, TX 77058 | (713)483-1166<br>(713)483-1164<br>FTS (713)525-1166 |
| Diane de Caix | NASA/JSC | Code DM6/Payload OPS<br>JSC, NASA, Houston, TX 77058 | (713)483-5542<br>FTS (713)525-5542 |
| John Glaese | Control Dynamics Co. | 600 Boulevard S. Suite 304<br>Huntsville, AL 35802 | (205)882-2650 |
| Ralph Knoll | MMDA/Denver | P. O. Box 179<br>Denver, CO 80201 | (303)977-4831 |
| Dave M. McGalthery | NASA/MSFC | FA-31<br>MSFC, AL 35812 | (205)544-0165 |

TETHERED SATELLITE SYSTEM / DYNAMICS AND CONTROL REVIEW PANEL
20 MARCH 1987
ATTENDANCE LIST

| NAME | COMPANY/AGENCY | MAILING ADDRESS | TELEPHONE NUMBER |
|---|---|---|---|
| Ron Humble | Lockheed/JSC | | (713)333-6285 |
| Norris Krone | NASA/ASAP | 6411 Ivey Lane<br>Greenbelt, Maryland 20770 | (301)345-8664 |
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# Minutes
# of
# Tethered Satellite System Dynamics and Control Review Panel
# First Panel Meeting
# March 20, 1987

## Control Dynamics Company
## Huntsville, Alabama

The first meeting of the Tethered Satellite System (TSS) Dynamics and Control Review Panel meeting was held on Friday March 20, 1987 at the facilities of Control Dynamics Company in Huntsville, Alabama. Approximately thirty (35) persons from NASA, Academia and Industry attended the meeting. TSS Panel Members in attendance were Dr. Jerrell Mitchell of Ohio University, Dr. Norris Krone of NASA Headquarters, Dr. Dan DeBra of Stanford University, Dr. Leonard Meirovitch of Virginia Polytechnic Institute and State University, and Dr. H. Eugene Worley of Control Dynamics Company (Chairman). Dr. Owen Garriott, the other Panel member, was unable to attend because of prior commitments. The meeting attendance list is included as Attachment B to this note. The meeting Agenda is included as Attachment C. (Some changes to the agenda were adjusted to real-time developments.) The welcome address was given by Mr. Sidney Saucier of NASA/Marshall Space Flight Center(MSFC). He stressed the importance of the panels activity to the eventual success of the TSS project in general and to the first flight in particular. The meeting was then turned over to Dr. Worley who reviewed the charge to the Panel and introduced the order of business.

The first presenter, Mr. Jayson Cowley, represented Martin Marietta Denver Aerospace (MMDA). He gave the Panel an overview of the TSS Project from a MMDA perspective with a description of the hardware, schedule, and the status. This presentation stimulated much discussion and many questions regarding the current configuration and how this configuration was driven by requirements and effected by history. There was a side discussion regarding the place and applicability of

schedule, and the status. This presentation stimulated much discussion and many questions regarding the current configuration and how this configuration was driven by requirements and effected by history. There was a side discussion regarding the place and applicability of Safety Reviews and the applicability of these reviews to this panels activities. It is the opinion of the Chairman that these discussions were outside the scope of the Panel activities. Any actions to the contrary should be addressed at the next meeting.

Next Mr. Keith Mowery of MSFC introduced the TSS Dynamics and Working Group with a brief discussion of their activities. Other dynamics and controls activities from a MSFC perspective were presented by Mr. Zachary Galaboff.

Dr. Carl Bodley of MMDA was the next presenter. He discussed MMDA TSS activities in the dynamics and controls areas. Because of the limited time available for Dr. Bodley, his presentation was necessarily limited to just presenting the bare essentials. There were many questions and comments from the Panel, of course, regarding this presentation. It is expected that this subject will be a major item at the next meeting.

Next Dr. Dave Arnold of the Smithsonian Astrophysical Observatory (SAO) gave a brief overview of their analytical work in the TSS area. He indicated that there was some disagreement between his work and that of other investigators. The Panel would like to give SAO an opportunity to discuss in detail their work at the next Panel meeting.

Mr. Gary Graybeal and Mr. Claude Nicollier of NASA/JSC described the dynamics and controls activities ongoing at the Johnson Space Center (JSC) with particular emphasis on the Shuttle Engineering Simulator (SES). Their work addresses the problem primarily from the astronaut perspective with emphasis on close-in recovery techniques and attendant astronaut safety. The Panel is particularly interested in the underlying assumptions and

dynamic models contained in the SES. The references to performance of the system in the presence of slack tethers must be viewed in the light of the dynamic modeling of the slack tether. JSC then presented an interesting twenty minute movie showing some of their graphical simulation results on the SES facility depicting the final six hundred (600) feet of the tethered satellite retrieval.

The meeting was adjourned with a discussion of the next meeting to be held toward the later part of MAY. {Subsequent discussions have changed the date of this meeting to June 24 and 25}. Each of the Panel Members were asked to submit written comments to the Panel Chairman as soon as possible.

# APPENDIX D

## SECOND PANEL MEETING AGENDA

TETHERED SATELLITE SYSTEM

DYNAMICS AND CONTROL REVIEW

PANEL MEETING NO. 2

June 24 - 25, 1987

Wednesday, June 24, 1987

| | | |
|---|---|---|
| 08:30 - 08:40 | Introduction of Session - Welcome | E. Worley (CDC) |
| 08:40 - 09:00 | Review of Charge to Panel Members | J. Price (MSFC) |
| 09:00 - 10:30 | Description of TSS Satellite Design<br>- Control System Design Requirements and Analysis<br>- Critical Components/Hazards Analyses<br>- Verification and Validation Test Program<br>- Auto-reconfigutation | PSN/AIT |
| 10:30 - 10:45 | Break | |
| 10:45 - 11:05 | TSS Simulation/Validation Focus | Z. Galaboff (MSFC) |
| 11:05 - 12:00 | TSS Simulation/Modeling Status | D. Tomlin/F. Vinz (MSFC) |
| 12:00 - 12:30 | Lunch | |

TETHERED SATELLITE SYSTEM

DYNAMICS AND CONTROL REVIEW

PANEL MEETING NO. 2

June 24 - 25, 1987

Wednesday, June 24, 1987

| | | |
|---|---|---|
| 12:30 - 02:00 | TSS Dynamics and Control Simulation Studies<br>- Slack Tether/Pendulous Motion<br>- Severed Tether Dynamics<br>- "Skip Rope" Mode<br>- Simulation Results/Comparisons | SAO |
| 02:00 - 02:15 | Break | |
| 02:15 - 04:00 | Shuttle Engineering Simulation (SES) Studies/Modeling<br>- Validation of Analysis Tools<br>- Results/Comparison Using Common Input Parameters<br>- Close Proximity Operations Simulation Results<br>- Crew Assessment of Retrieval Operations/ Critical Human Interfaces<br>- Slack Tether/Pendulous Motion/Passive Retrieval Studies | JSC |
| 04:00 - 05:00 | Discussion and Planning | E. Worley (CDC) |
| 05:00 | Adjourn | |

TETHERED SATELLITE SYSTEM
DYNAMICS AND CONTROL REVIEW
PANEL MEETING NO. 2

June 24 - 25, 1987

Thursday, June 25, 1987

| | | |
|---|---|---|
| 08:30 - 08:40 | Introduction of Session | E. Worley (CDC) |
| 08:40 - 10:30 | TSS Program Requirements/Objectives | MMDA |

- Flow down of TSS Requirements to the Hardware Selection Process

- Specific Dynamic and Control Requirements as Levied on the Design of Deployer Hardware Elements
  - Boom Dynamic Properties
  - Tether Dynamic Properties
  - Electrical Motor Characteristics
  - Computer Sizing, Sample Rate, etc.
  - Instrumentation

- Hardware Description
  - Block Diagrams/Schematics/Logic of Hardware Elements
  - Specific Dynamic Characteristics of Subsystems (i.e., Motors, Brakes, Tether and Operational Constraints/Anomalies and Impacts
  - Flight Instrumentation Required to Analyze Dynamic Behavior of the System
  - Test Program for Hardware Performance Validation Verification

| | | |
|---|---|---|
| 10:30 - 10:45 | Break | |

TETHERED SATELLITE SYSTEM
DYNAMICS AND CONTROL REVIEW
PANEL MEETING NO. 2

June 24 - 25, 1987

Thursday, June 25, 1987

| | | |
|---|---|---|
| 10:45 - 12:00 | Baseline Mission Profile<br>- Nominal Mission<br>- Actions Required and Planned Responses to Off-Nominal Conditions and Failures<br>- Operational Hazards Analysis/Study Plan<br>- Real Time Support Required and Planned | MMDA |
| 12:00 - 12:30 | Lunch | |
| 12:30 - 01:00 | TSS Control System Description | MMDA |

- Control System Block Diagram
  - Measured and Estimated States
  - Analog and Digital Elements/Paths
  - All Dynamic Elements
- Control System Linear Stability and Response Results
- Control System Trade Studies to Access Robustness and Sensitivity to Uncertainties
- Degrees of Coupling to Orbiter and Satellite Control Action
- On-Orbit Tuning of Parameters

TETHERED SATELLITE SYSTEM
DYNAMICS AND CONTROL REVIEW
PANEL MEETING NO. 2

June 24 - 25, 1987

Thursday, June 25, 1987

| | | |
|---|---|---|
| 01:00 - 02:00 | Description of Simulation/Analysis Tools | MMDA |

- Required Computer Simulation/Modeling
  - Low Fidelity/Validation
  - High Fidelity/Validation
- Simulation Parameter Study Results
  - Parameter Studies that Indicate System Performance, (i.e, Trends and Conclusions)
  - Comparison of Parametric Data Trends with other Investigators. Note differences and explain
- Present Results of Current Hazards Analysis and Off-Nominal Retrieval Conditions that may Impact Successful Docking of TSS (i.e, Slack Tether, Pendulous Motion, Lack of System Damping, etc.)

| | | |
|---|---|---|
| 02:00 - 02:15 | Break | |
| 02:15 - 03:00 | Simulation/Analysis Results - Continued | MMDA |
| 03:00 - 04:30 | Revisiting of Key Issues from Previous Topics | E. Worley (CDC) |
| 04:30 - 05:00 | Discussions and Wrap-up Planning | E. Worley (CDC) |
| 05:00 | Adjourn | |

# APPENDIX E

## SECOND PANEL MEETING ATTENDEES LIST

TETHERED SATELLITE SYSTEM / DYNAMICS AND CONTROL REVIEW PANEL
24 JUNE 1987
ATTENDANCE LIST

| NAME | COMPANY/AGENCY | MAILING ADDRESS | TELEPHONE NUMBER |
|---|---|---|---|
| Charles E. Fleel | NASA /MSFC | ED-13 | 544-1450 |
| Don Tomlin | NASA/MSFC | ED13 | 544-1465 |
| JAY H. LAUE | NASA /msFc | NASA/MSFC/EA31 | (205) 544-0158 |
| N.N.CARR | NASA/JSC | NASA/JSC/DH64 | (713) 483-5533 |
| Carl Bodley | MMOA | Martin Marietta Box 179 Denver, 80201 Mail S8071 | (303) 977-3168 |
| Thomas Stuart | NASA/HQ | Code MA Washington, D.C. | (202) 453-1568 |
| Brooks Moore | Control Dynamics | Office Park South Huntsville, Ala | (205) 882-2650 |
| Chris Rupp | MSFC | PS04 MSFC AL 35812 | 205 5440627 |
| John Glaese | Control Dynamics | 600 Boulevard South Suite304 Huntsville, Al 35802 | 205-882-2650 |
| MARIO RHEINFURTH | MSFC | ED 01 | 205 - 544 - 1416 |
| Howard A. Flanders | MMDA | Marlon Marietta P.O. Box 179 Denver 80201 Mail S8071 | (303) 977-5951 |

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TETHERED SATELLITE SYSTEM / DYNAMICS AND CONTROL REVIEW PANEL
24 JUNE 1987
ATTENDANCE LIST

| NAME | COMPANY/AGENCY | MAILING ADDRESS | TELEPHONE NUMBER |
|---|---|---|---|
| YASHVANT JANI | LinCom Corporation | 18100 Upper bay Rd #1208<br>Houston, Texas, 77058 | 713-333-1625 |
| Richard Deppisch | NASA-JSC | NASA RD 1<br>Houston, Tx. 77058 | 713-483-8088 |
| LINDA BREWSTER | NASA-MSFC | | 544-0169 |
| DAVE McGLATHERY | NASA/MSFC | EA-31 | 205-544-0165 |
| MARION TEAL | NASA/MSFC | EB33<br>MSFC, AL, 35812 | 205-544-3704 |
| BILLY NUNLEY | NASA/MSFC | EJ61 | 205-544-6593 |
| James S. Spear | NASA/MSFC | ER44<br>MSFC AL. 35812 | 205-544-3818 |
| MICHAEL LAIBLIE | JSC/RS16C | RS16C (ROCKWELL)<br>600 GEMINI<br>HOUSTON, TX. 77058 | (713)-282-2785 |
| CARL SODERLAND | JSC/EH2 | NASA-JSC/EH2<br>HOUSTON, TX 77058 | (713) 483-8301 |
| ROGER WACKER | LEMSCO/JSC | LEMSCO B16<br>HOUSTON, TX | (713) 333-6962 |
| FRANK VINZ | MSFC/EB44 | EB44<br>MSFC<br>HUNTSVILLE, AL 35812 | 205-544-3802 |

TETHERED SATELLITE SYSTEM / DYNAMICS AND CONTROL REVIEW PANEL
24 JUNE 1987
ATTENDANCE LIST

| NAME | COMPANY/AGENCY | MAILING ADDRESS | TELEPHONE NUMBER |
|---|---|---|---|
| JAYSON COWLEY | MARTIN MARIETTA | P.O Box 179 MS S8071<br>DENVER Co 80201 | (303)977-3256 |
| RALPH KNOLL | MMDA | P. O. Box 179 S 8071<br>DENVER CO 80201 | (303) 971-4831 |
| CLAUDE NICOLLIER | NASA / JSC | Office code CB<br>NASA Johnson Space Center<br>HOUSTON, TX 77058 | (713) 483-2734 |
| DAVID ARNOLD | SMITHSONIAN ASTROPHYSICAL OBSERVATORY | MAIL STOP 59<br>60 GARDEN ST<br>CAMBRIDGE, MA. 02138 | (617) 495-7269<br>FTS 830-7269 |
| ANDREA LORENZONI | PSN/CNR | PSN/CNR - VIALE<br>REGINA MARGHERITA<br>202 - 00195 ROME-ITALY | 39-6-4767259 |
| Bruno' Musetti | AERITALIA | Aeritalia Saipa.<br>c/o MARCHE 41 10100 TORINO<br>ITALY - 011-33322752 | 39-11-3332752 |
| GENE COMPTON | NASA/MSFC/AER | AERITALIA SAIPA<br>CORSO MARCHE 41<br>10100 TORINO | 39-11-720239 |
| JOHN GATTIS | NASA/MSFC | NASA / MSFC<br>EA31<br>MSFC AL. 35812 | 544-0163 |
| SHERMAN SELTZER | CONTROL DYNAMICS | HUNTSVILLE, AL. | (205) 882-2630 |
| KEITH MOWERY | NASA/MSFC/ED13 | ED 13<br>NASA/MSFC | 544-1444 |
| ZACHARY J. GALABOFF | NASA/MSFC | ED 13<br>MARSHALL SPACE FLIGHT CENTER<br>HUNTSVILLE, AL 35812 | 544-1446 |

TETHERED SATELLITE SYSTEM / DYNAMICS AND CONTROL REVIEW PANEL
24 JUNE 1987
ATTENDANCE LIST

| NAME | COMPANY/AGENCY | MAILING ADDRESS | TELEPHONE NUMBER |
|---|---|---|---|
| Jack MacPherson | NASA / MSFC | EJ 61 | (205) 544-6626 |
| Joe Howell | NASA / MSFC | EJ 61 | (205) 544-4285 |
| Bill Bollendonk | MMDA Denver | P.O. Box 179<br>Denver, Colo.<br>80120 | 303-977-0965 |
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# APPENDIX F

# PRESENTATION SUMMARIZING FIRST TWO PANEL MEETINGS

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### AGENDA

- INTRODUCTION
- PANEL STRUCTURE
  - PURPOSE
  - MEMBERSHIP
  - SCHEDULE
  - OPERATIONS
- PRELIMINARY FINDINGS
  - TETHERED SATELLITE SYSTEM
  - SATELLITE
- PRELIMINARY RECOMMENDATIONS
- PLANS

2-2266-7-17

Marshall Space Flight Center

# Tethered Satellite System

## DYNAMICS AND CONTROL AND REVIEW PANEL

Purpose: Conduct a thorough and independent review of the performance, dynamics, control, and mission safety aspects of flying the TSS onboard the Shuttle in late 1990.

Tasks: Review/assess TSS dynamics and control work being performed by the prime contractor and other organizations supporting the TSS analysis effort.

Report on the adequacy and completeness of the present ongoing effort.

Report findings concerning the need for additional modeling, simulation, ground/space experimentation, and/or theoretical work in the field of dynamics and control.

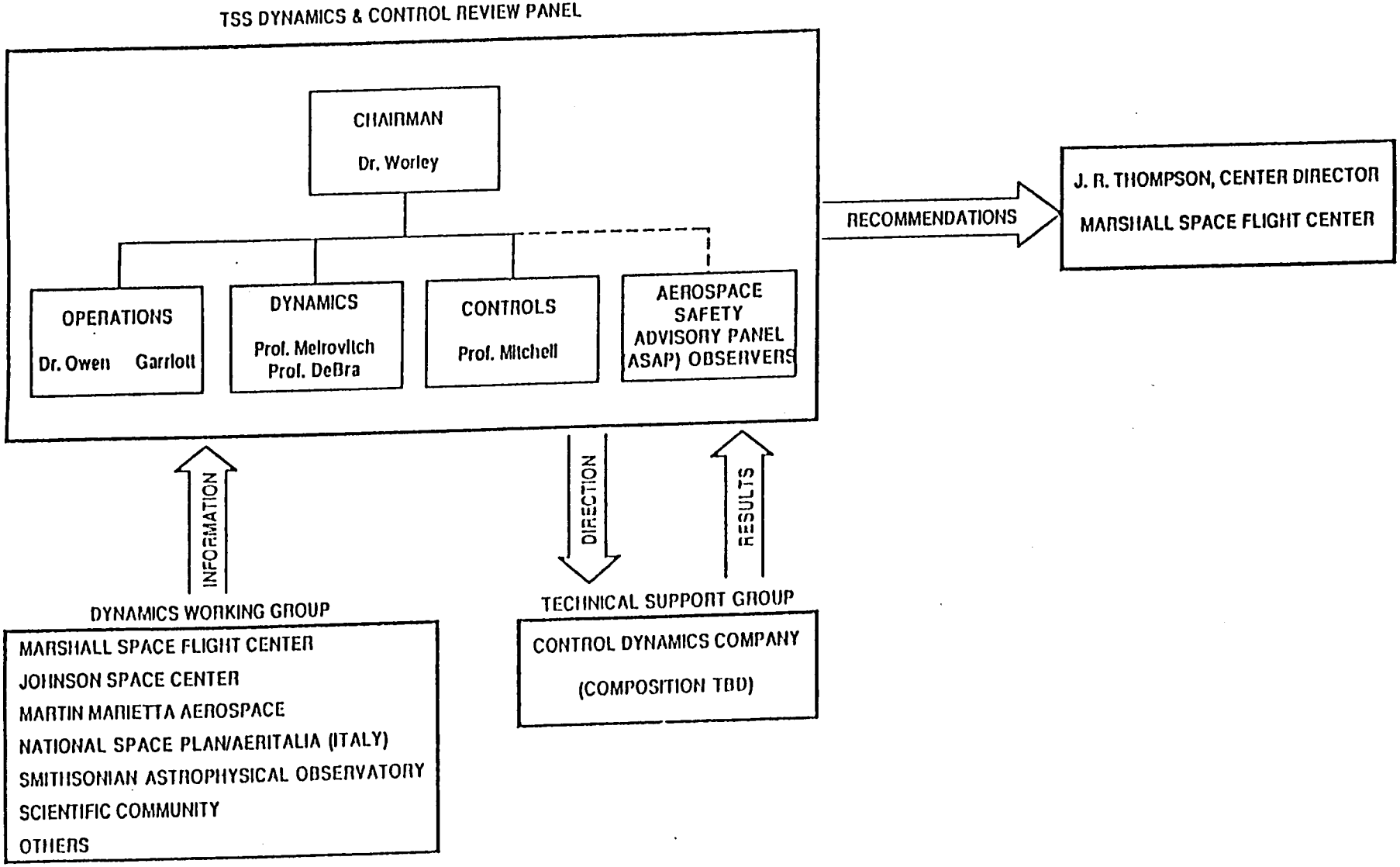
(Reference: Letters to panel members from James R. Thompson, Jr., dated March 2, 1987)

2-2240-7-17

Marshall Space Flight Center

Tethered Satellite System

# TSS DYNAMICS & CONTROL REVIEW PANEL ORGANIZATION & DATA FLOW

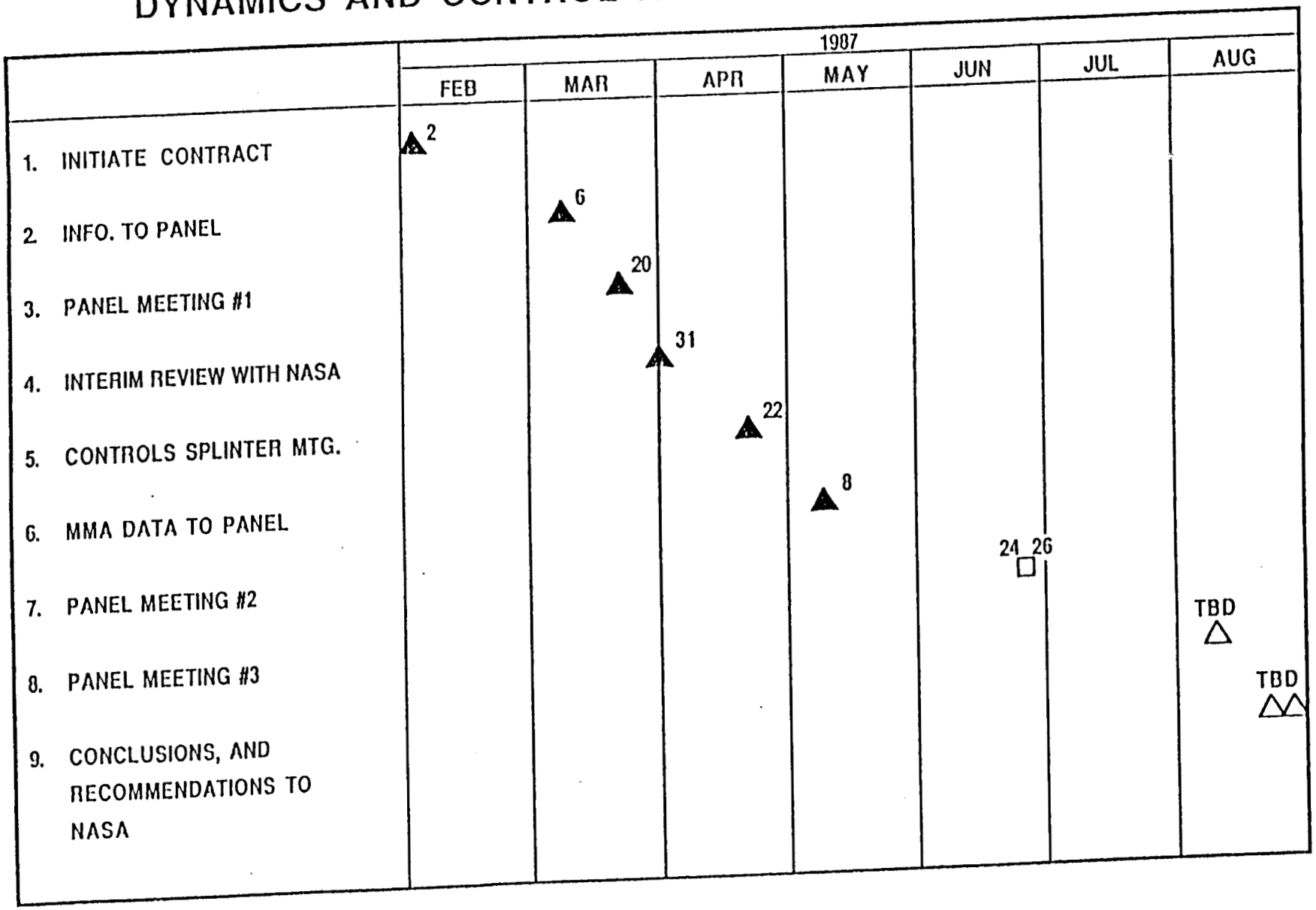


2-2252-7-17

Marshall Space Flight Center

# Tethered Satellite System

## DYNAMICS AND CONTROL REVIEW PANEL SCHEDULE



# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### OPERATIONS

- Telecon with Each Member
- "Hamburger" Attitude Initialization
- 1st Formal Review
- Telecon Follow-Ups
- Controls Review at MMDA
- Telecons Planning for 2nd Meeting
- 2nd Formal Review
- Panel Only Follow-Up

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### PRELIMINARY FINDINGS - SYSTEM

- TSS program is understood as an important link in NASA's future space operations.
- Good mechanical design - no apparent flaws.
- But TSS backed by little or no analysis. Rather, design is based on simulation alone.
- Control design is too complicated and too restrictive.
- Off-nominal operation studies not adequate.
  - Unplanned Events
  - Off-Nominal Parameters
  - Slack Tether
- SAO contribution needs to be focused.
- Management has been steamrollered by technical fancy footwork.
- No integrated simulation of Shuttle/TSS/Satellite in evidence.

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### PRELIMINARY FINDINGS - SUBSATELLITE

- Control System Analysis Not Presented
- Design Is Questionable To Not Acceptable
  - 6 - 9 Period Sample Delay
  - No Flexible Body Effects Included
  - Integrated Sim Lacking
- Further Coordination Mandatory

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### PRELIMINARY RECOMMENDATIONS

- Get a tighter rein on the technical analysis activities.
- Develop a detailed-comprehensive simulation including all significant effects.
- Provide some additional muscle for S&E Chief Engineer.
- Review State-of-the-Art outside TSS program for applicability, e.g. "Space Tethers for Science in the Space Station Era" Conference.
- Extend Panel activities to include review of integrated test/analysis/simulation program.

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### PLANS

Near Term:

- Develop Final Recommendations
- Develop Final Report
- Present Findings To NASA/MSFC (Late August)
- Continue March Past Current Termination Point

CONTROL DYNAMICS COMPANY

# APPENDIX G

# STATUS PRESENTATION OF PANEL ACTIVITIES AND RECOMMENDATIONS

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

REVIEW
SEPT. 1, 1987

CONTROL DYNAMICS COMPANY
600 BOULEVARD SOUTH, SUITE 304
HUNTSVILLE, ALABAMA 35802

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## REVIEW
## SEPT. 1, 1987

## AGENDA

A. INTRODUCTION

B. PANEL CHARTER / SCHEDULE / MEMBERSHIP

C. REVIEW OF PREVIOUS PRESENTATION

D. KEY SYSTEM ISSUES AND CONCERNS

E. SYSTEM RECOMMENDATIONS

F. KEY SATELLITE ISSUES AND CONCERNS

G. SATELLITE RECOMMENDATIONS

H. FUTURE ACTIVITIES

I. SUMMARY / CONCLUSIONS

2-2266-7-17

Marshall Space Flight Center

# Tethered Satellite System

## DYNAMICS AND CONTROL AND REVIEW PANEL

Purpose: Conduct a thorough and independent review of the performance, dynamics, control, and mission safety aspects of flying the TSS onboard the Shuttle in late 1990.

Tasks: Review/assess TSS dynamics and control work being performed by the prime contractor and other organizations supporting the TSS analysis effort.

Report on the adequacy and completeness of the present ongoing effort.

Report findings concerning the need for additional modeling, simulation, ground/space experimentation, and/or theoretical work in the field of dynamics and control.

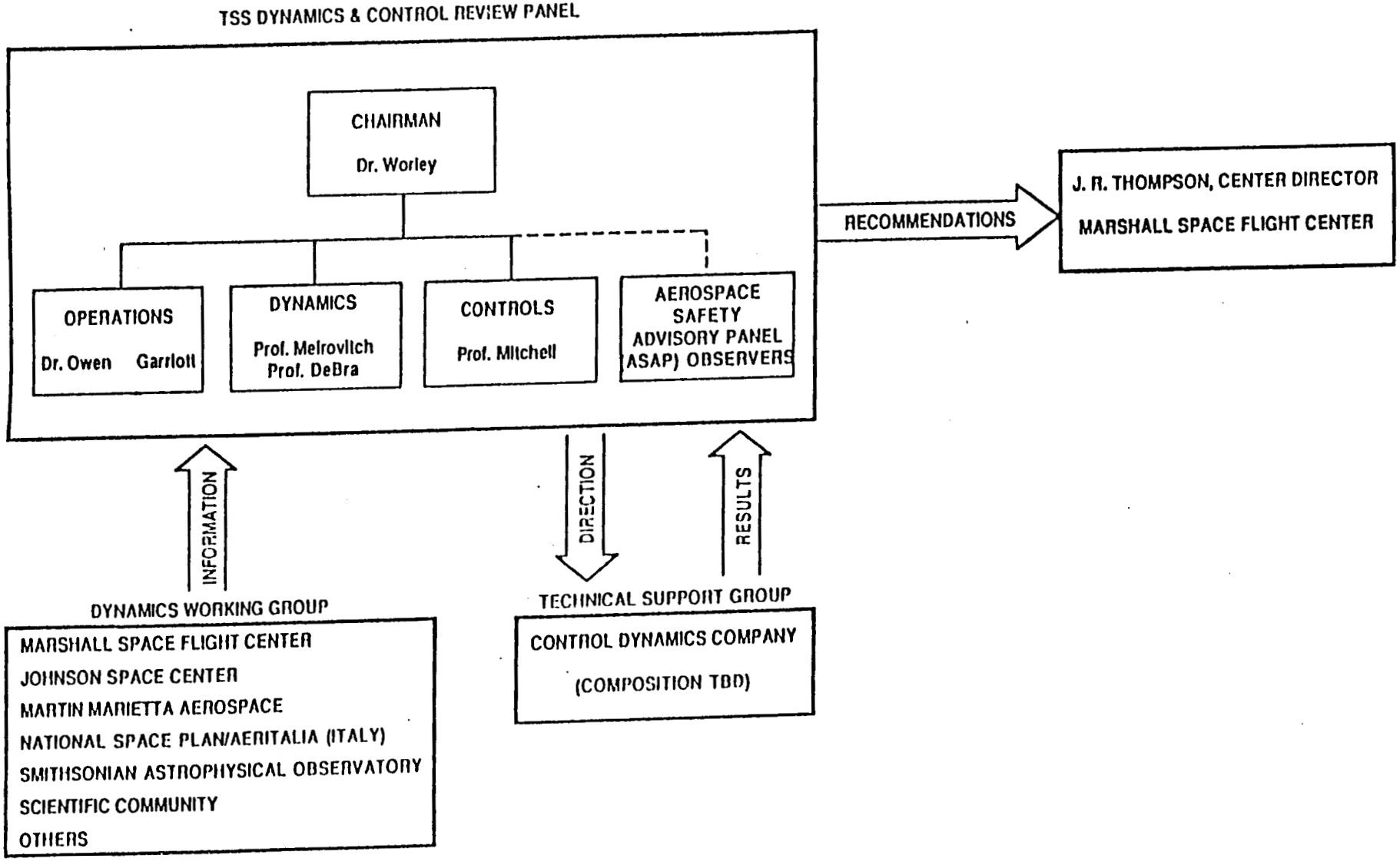
(Reference: Letters to panel members from James R. Thompson, Jr., dated March 2, 1987)

2-2240-7-17

Marshall Space Flight Center

# Tethered Satellite System

## TSS DYNAMICS & CONTROL REVIEW PANEL ORGANIZATION & DATA FLOW



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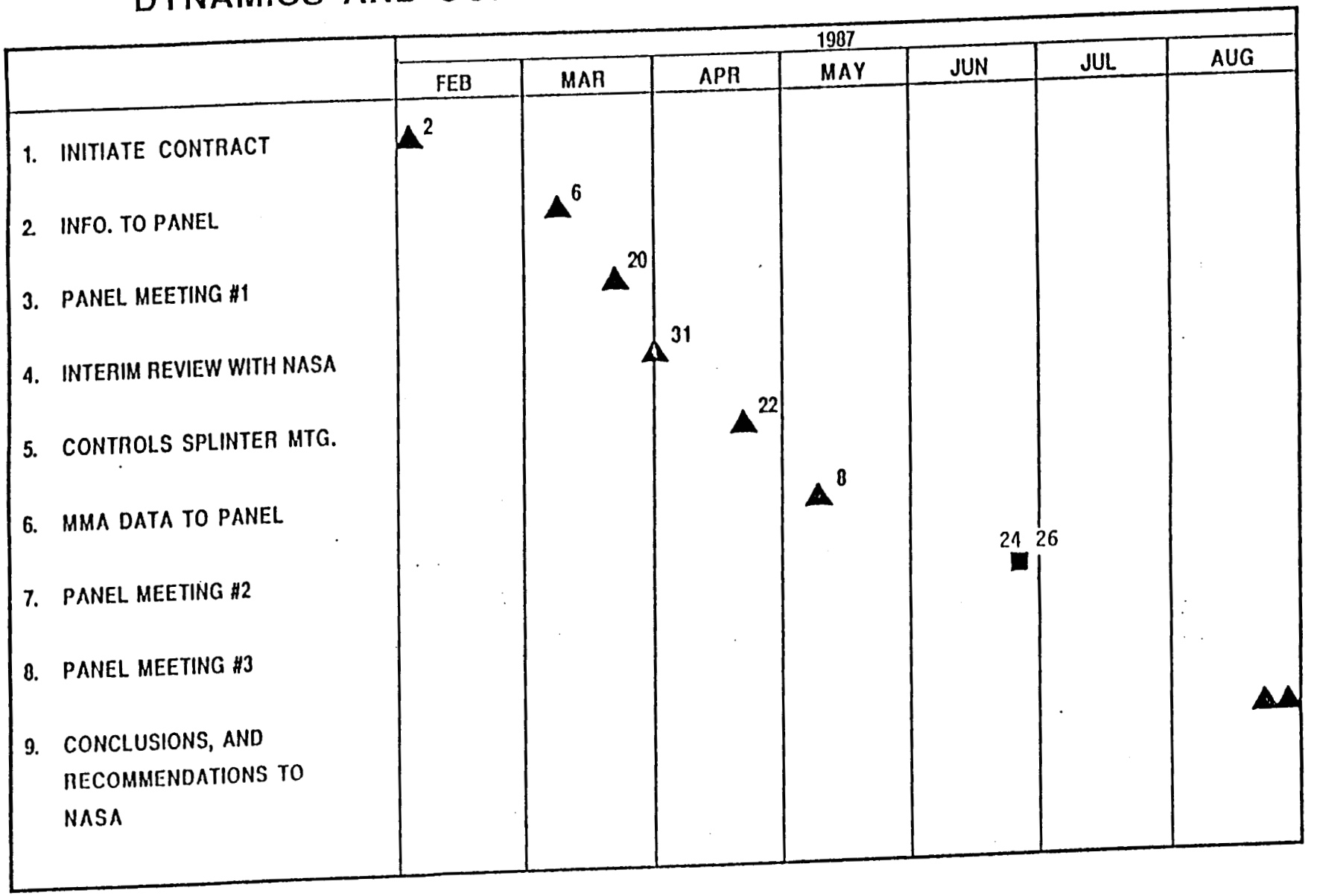
Marshall Space Flight Center

Tethered Satellite System

# DYNAMICS AND CONTROL REVIEW PANEL SCHEDULE



# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### PRELIMINARY FINDINGS - SYSTEM

- TSS program is understood as an important link in NASA's future space operations.
- Good mechanical design - no apparent flaws.
- But TSS backed by little or no analysis. Rather, design is based on simulation alone.
- Control design is too complicated and too restrictive.
- Off-nominal operation studies not adequate.
  - Unplanned Events
  - Off-Nominal Parameters
  - Slack Tether
- SAO contribution needs to be focused.
- Management has been steamrollered by technical fancy footwork.
- Engineering design and analysis of retrieval MUST not be relegated to JSC!
- No integrated simulation of Shuttle/TSS/Satellite in evidence.

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### PRELIMINARY FINDINGS - SUBSATELLITE

- Control System Analysis Not Presented
- Design Is Questionable To Not Acceptable
  - 6 - 9 Period Sample Delay
  - No Flexible Body Effects Included
  - Integrated Sim Lacking
- Further Coordination Mandatory

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review
## July 7, 1987

### PRELIMINARY RECOMMENDATIONS

- Get a tighter rein on the technical analysis activities. √
- Develop a detailed-comprehensive simulation including all significant effects. ?
- Provide some additional muscle for S&E Chief Engineer. √
- Review State-of-the-Art outside TSS program for applicability, e.g. "Space Tethers for Science in the Space Station Era" Conference. √
- Extend Panel activities to include review of integrated test/analysis/simulation program. ?

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

D. KEY SYSTEM ISSUES AND CONCERNS

1. SYSTEM ANALYSES NOT ADEQUATE

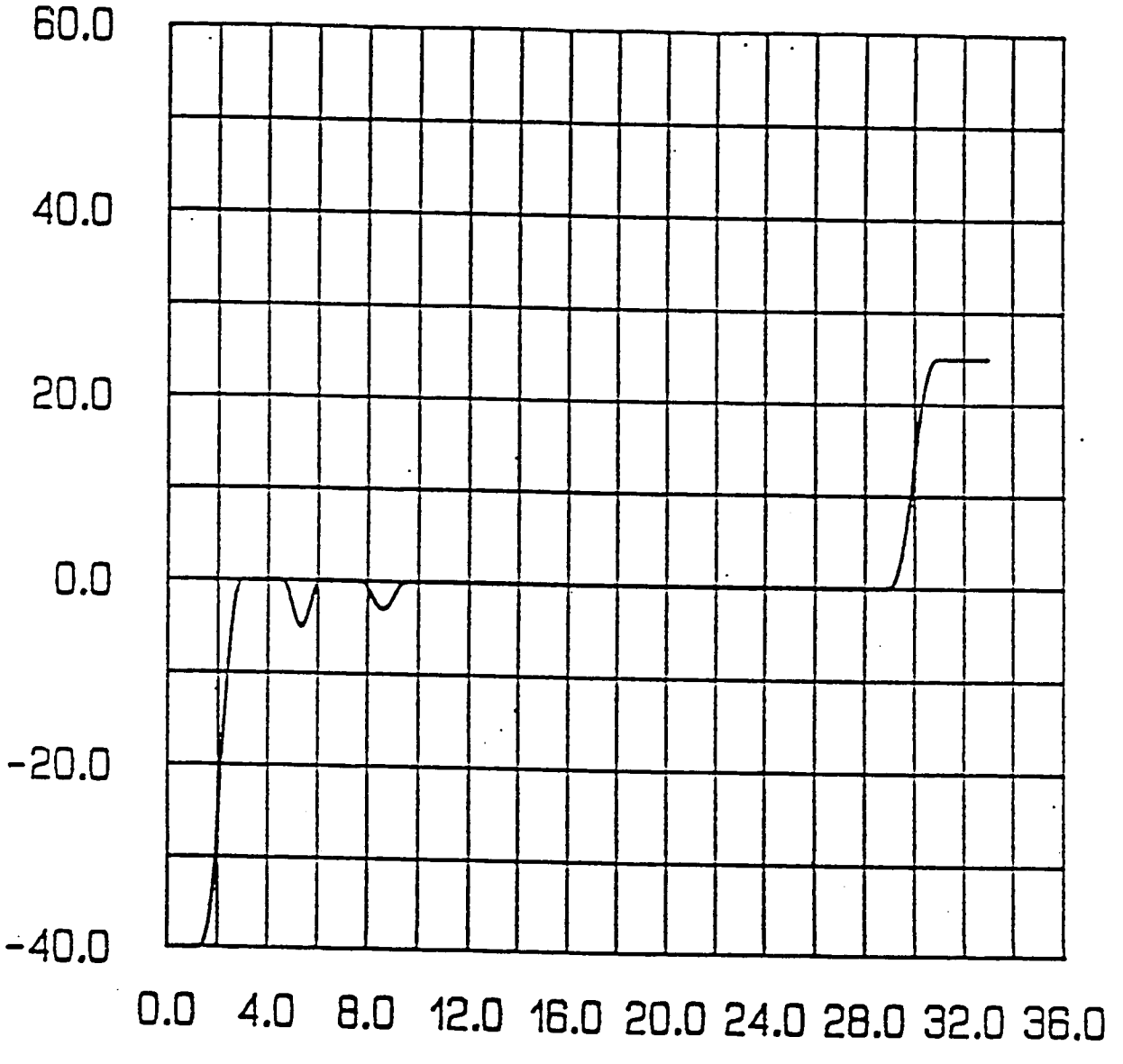
   a) SENSOR / INSTRUMENTATION REQUIREMENTS
   b) COMPONENT TESTING
   c) SYSTEM PERFORMANCE
   d) SAFETY

2. GUIDANCE & CONTROL TOO COMPLICATED AND TOO RESTRICTIVE

   a) MISSION FLEXIBILITY
   b) MISSION ROBUSTNESS / SUCCESS
   c) SAFETY

3. INTEGRATED SIMULATION / TESTING PROGRAM NOT IN EVIDENCE

   a) MISSION ROBUSTNESS / SUCCESS
   b) SAFETY




Fri Jul 31 19:01 1987 TSSERVO BASELINE MISSION-1 PROFILE

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## E. SYSTEM RECOMMENDATIONS

1. PROVIDE, AT AN APPROPRIATE FUTURE TIME, A DETAILED REVIEW OF THE G&C CONCEPT WITH SUPPORTING PARAMETER STUDIES.

2. REVIEW CURRENT AND PRESENT COMPONENT AND SYSTEM TEST IN GREATER DETAIL WITH EMPHASIS ON INTERRELATIONSHIPS AND REQUIREMENTS.

   a) BENCH TESTS
      1) CAN BE PERFORMED EARLY
      2) ARE RELATIVELY INEXPENSIVE

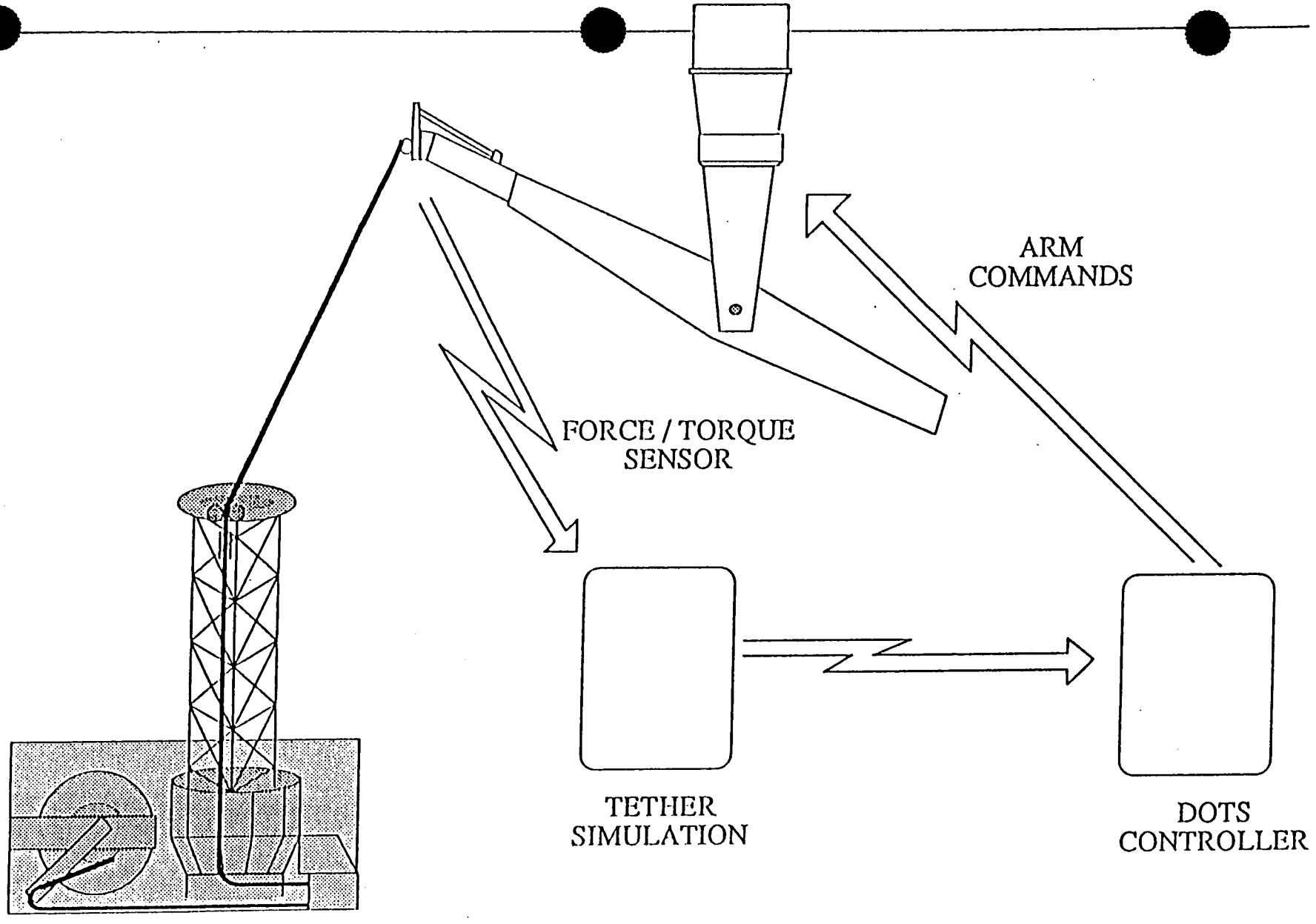
   b) SYSTEM TESTS
      1) MMDA PRESENTATIONS DID NOT PROVIDE COMPLETE DESCRIPTION OF TEST UNDER CONSIDERATION.
      2) MSFC HAS UNIQUE FACILITIES FOR THIS PROGRAM.

3. DEVELOP AND PRESENT A DETAILED SIMULATION PLAN SHOWING INTERRELATION BETWEEN VARIOUS SIMULATIONS IN GOVERNMENT AND IN INDUSTRY.

4. FOCUS SAO ACTIVITIES ON TOUGH TECHNICAL ISSUES WITH DEFINED OUTPUT (e.g. SLACK TETHER DYNAMICS AND EFFECTS).

5. TASK PANEL TO REPORT ON THEIR OWN INDEPENDENT THOUGHTS BASED ON OUR REVIEW OF THE CURRENT STATE-OF-THE-ART.

   a) REVIEW OTHER TETHER ACTIVITIES
   b) ANALYZE PASSIVE DEPLOYMENT AND RETRIEVAL




TSS in the Robotics / Flat Floor Facility

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

F. KEY SATELLITE ISSUES AND CONCERNS

1. CONTROL DESIGN APPEARS TO BE INADEQUATE. NOT ENOUGH INFORMATION PRESENTED.

   a) SAMPLING EFFECTS
   b) FLEXIBLE BODY EFFECTS
   c) SYSTEM COUPLING EFFECTS

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

G. SATELLITE RECOMMENDATIONS

1. FURTHER DISCUSSION IS MANDATORY

   TECHNICAL INTERCHANGE PLANNED WITH AERITALIA ON OCTOBER 9 11, AND 12

2. RESULTS OF THESE MEETINGS WILL BE DOCUMENTED

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

H. FUTURE ACTIVITIES

1. REVIEW AERITALIA DESIGN

2. INVESTIGATE PASSIVE RETRIEVAL

3. PREPARE PRESENTATION ON TETHER DYNAMICS STUDIES OUTSIDE OF TSS PROGRAM

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

I. SUMMARY / CONCLUSIONS

1. HEALTHY SPIRIT OF COOPERATION AND INFORMATION EXCHANGE EXISTS AT MSFC.

2. PANEL ACTIVITIES HAVE BEEN CONSTRUCTIVE.

3. FUTURE WORK IS REQUIRED

4. THANK YOU FOR THE OPPORTUNITY TO HELP!

# APPENDIX H

# RESULTS FROM SECOND PANEL MEETING

October 12, 1987

A. INTRODUCTION

B. REVIEW OF PANEL ACTIVITIES

C. REVIEW OF TSS SATELLITE MEASUREMENT AND CONTROL SYSTEM

1. SYSTEMS OVERVIEW

2. CONCERNS

3. SUMMARY

D. REVIEW OF SPECIFIC PANEL QUESTIONS

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

REVIEW
SEPT. 1, 1987

CONTROL DYNAMICS COMPANY
600 BOULEVARD SOUTH, SUITE 304
HUNTSVILLE, ALABAMA 35802

2-2268-7-17

Marshall Space Flight Center

# Tethered Satellite System

## DYNAMICS AND CONTROL AND REVIEW PANEL

Purpose: Conduct a thorough and independent review of the performance, dynamics, control, and mission safety aspects of flying the TSS onboard the Shuttle in late 1990.

Tasks: Review/assess TSS dynamics and control work being performed by the prime contractor and other organizations supporting the TSS analysis effort.

Report on the adequacy and completeness of the present ongoing effort.

Report findings concerning the need for additional modeling, simulation, ground/space experimentation, and/or theoretical work in the field of dynamics and control.

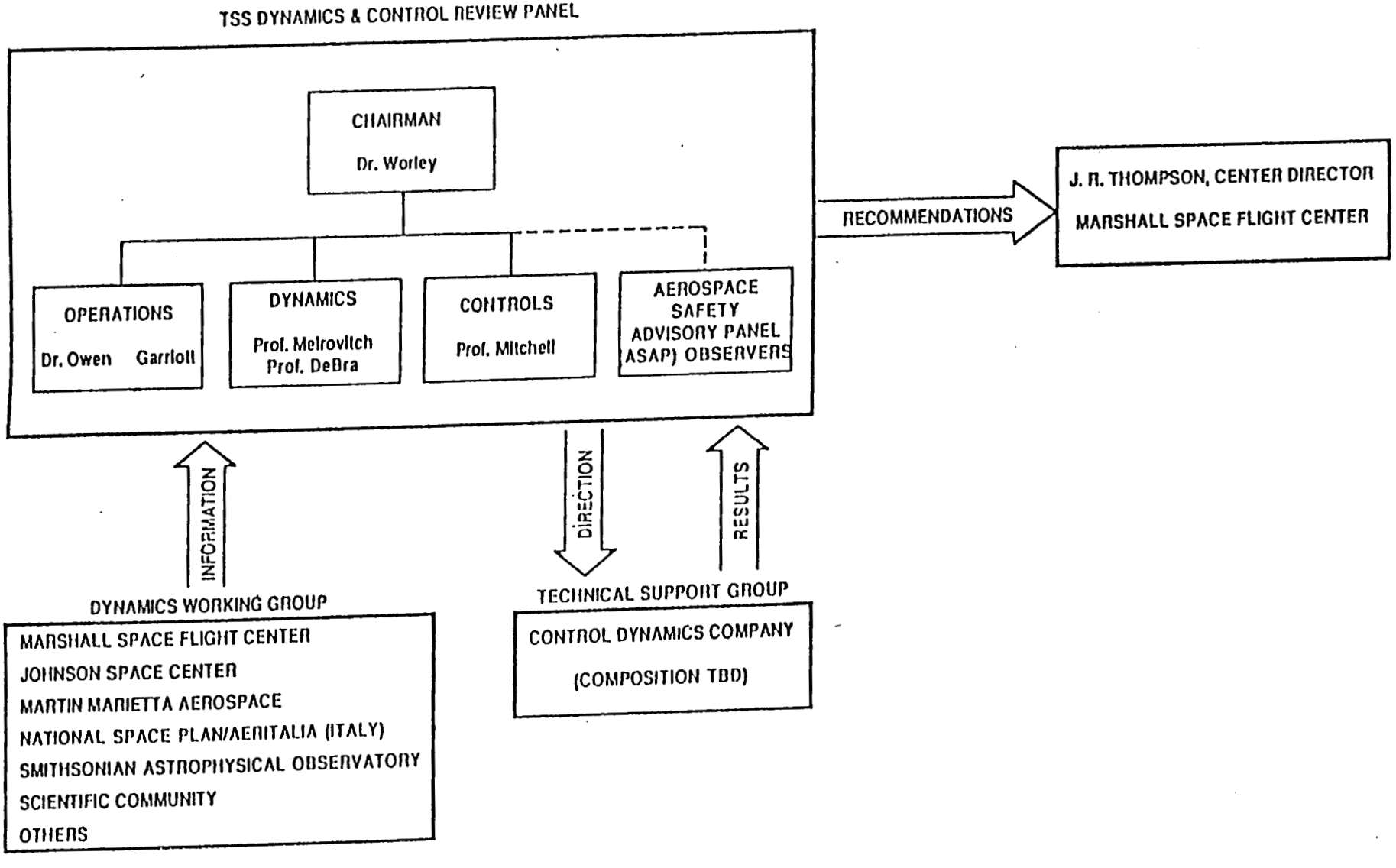
(Reference: Letters to panel members from James R. Thompson, Jr., dated March 2, 1987)

2-2240-7-17

Marshall Space Flight Center

# Tethered Satellite System

## TSS DYNAMICS & CONTROL REVIEW PANEL ORGANIZATION & DATA FLOW



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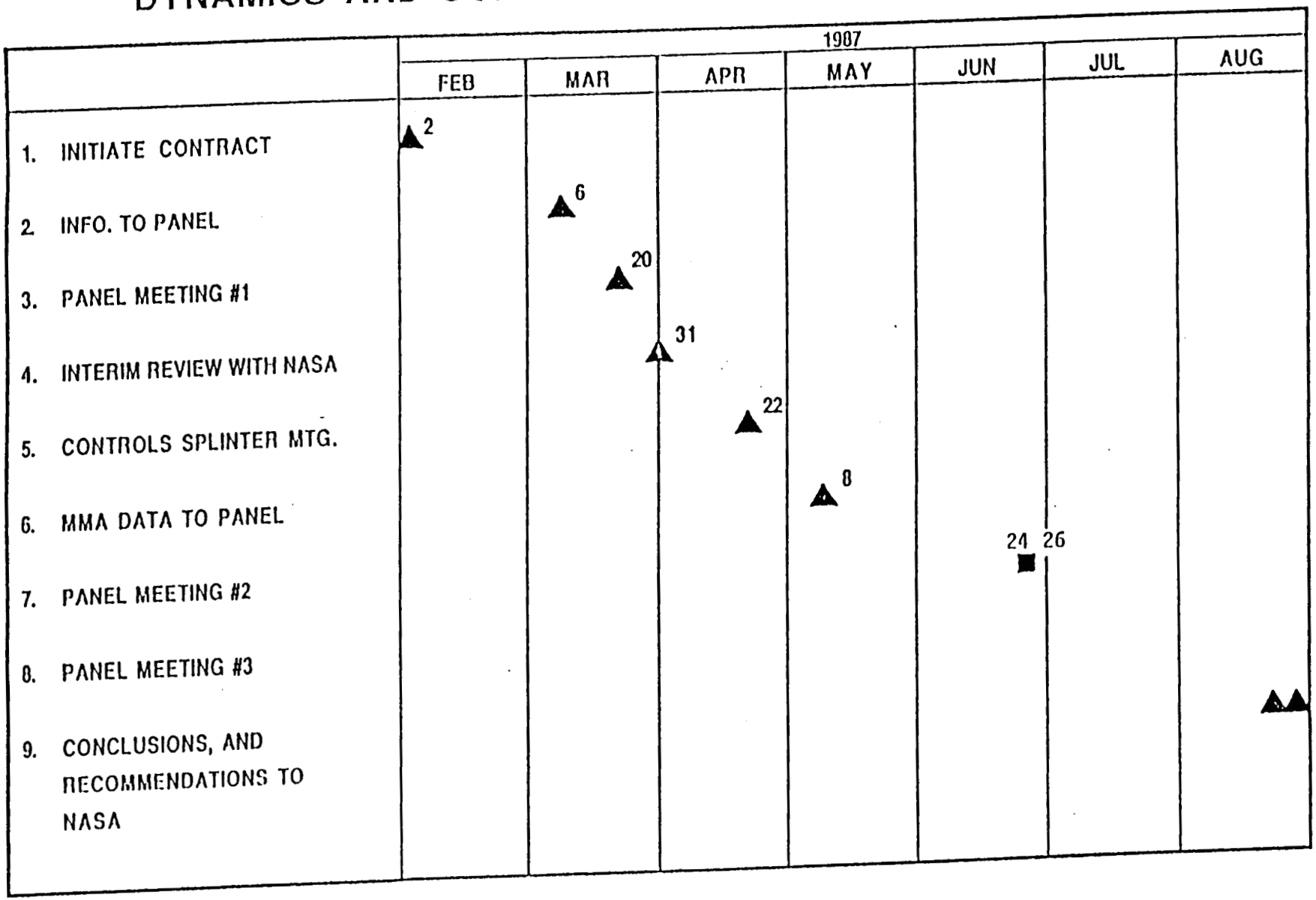
Marshall Space Flight Center

# Tethered Satellite System

## DYNAMICS AND CONTROL REVIEW PANEL SCHEDULE



# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### PRELIMINARY FINDINGS - TECHNICAL

- TSS program is understood as an important link in NASA's future space operations.
- Good mechanical design - no apparent flaws.
- But TSS backed by little or no analysis. Rather, design is based on simulation alone.
- Control design is too complicated and too restrictive.
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- No integrated simulation of Shuttle/TSS/Satellite in evidence.

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## Status Review

## July 7, 1987

### PRELIMINARY RECOMMENDATIONS

- Get a tighter rein on the technical analysis activities. √
- Develop a detailed-comprehensive simulation including all significant effects?
- Review State-of-the-Art outside TSS program for applicability, e.g. "Space Tethers for Science in the Space Station Era" Conference. √
- Extend Panel activities to include review of integrated test/analysis/simulation program?

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

D. KEY SYSTEM ISSUES AND CONCERNS

1. SYSTEM ANALYSES NOT ADEQUATE

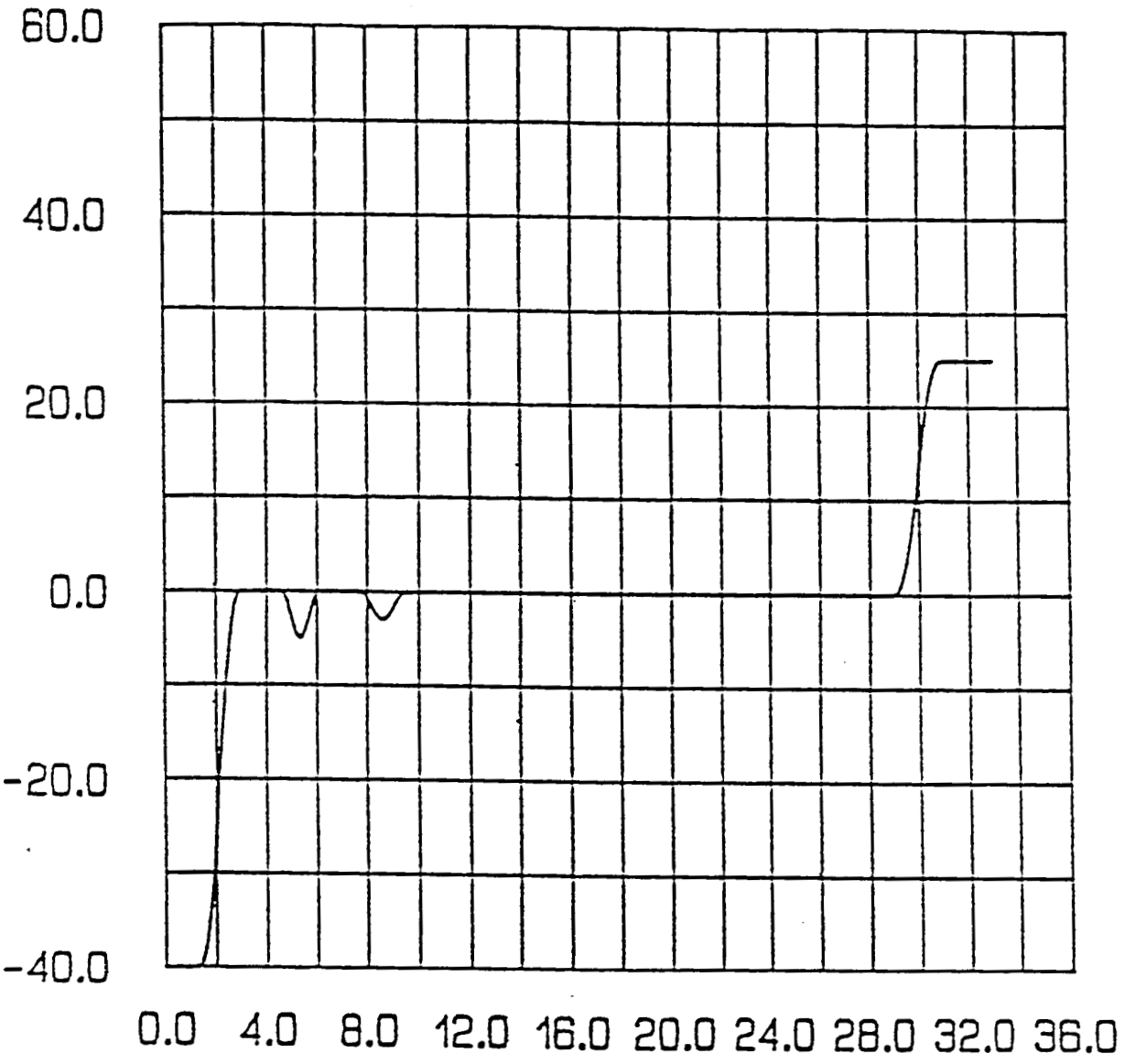
   a) SENSOR / INSTRUMENTATION REQUIREMENTS
   b) COMPONENT TESTING
   c) SYSTEM PERFORMANCE
   d) SAFETY

2. GUIDANCE & CONTROL TOO COMPLICATED AND TOO RESTRICTIVE

   a) MISSION FLEXIBILITY
   b) MISSION ROBUSTNESS / SUCCESS
   c) SAFETY

3. INTEGRATED SIMULATION / TESTING PROGRAM NOT IN EVIDENCE

   a) MISSION ROBUSTNESS / SUCCESS
   b) SAFETY




Fri Jul 31 19:01 1987 TSSERVO BASELINE MISSION-1 PROFILE

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

## E. SYSTEM RECOMMENDATIONS

1. PROVIDE, AT AN APPROPRIATE FUTURE TIME, A DETAILED REVIEW OF THE G&C CONCEPT WITH SUPPORTING PARAMETER STUDIES.

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5. TASK PANEL TO REPORT ON THEIR OWN INDEPENDENT THOUGHTS BASED ON OUR REVIEW OF THE CURRENT STATE-OF-THE-ART.

   a) REVIEW OTHER TETHER ACTIVITIES
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# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

G. SATELLITE RECOMMENDATIONS

1. FURTHER DISCUSSION IS MANDATORY

   TECHNICAL INTERCHANGE PLANNED WITH AERITALIA ON OCTOBER 9 11, AND 12

2. RESULTS OF THESE MEETINGS WILL BE DOCUMENTED

CONTROL DYNAMICS COMPANY

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

H. FUTURE ACTIVITIES

1. REVIEW AERITALIA DESIGN

2. INVESTIGATE PASSIVE RETRIEVAL

3. PREPARE PRESENTATION ON TETHER DYNAMICS STUDIES OUTSIDE OF TSS PROGRAM

CONTROL DYNAMICS COMPANY

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL REVIEW PANEL

I. SUMMARY / CONCLUSIONS

1. HEALTHY SPIRIT OF COOPERATION AND INFORMATION EXCHANGE EXISTS AT MSFC.

2. PANEL ACTIVITIES HAVE BEEN CONSTRUCTIVE.

3. FUTURE WORK IS REQUIRED

4. THANK YOU FOR THE OPPORTUNITY TO HELP!

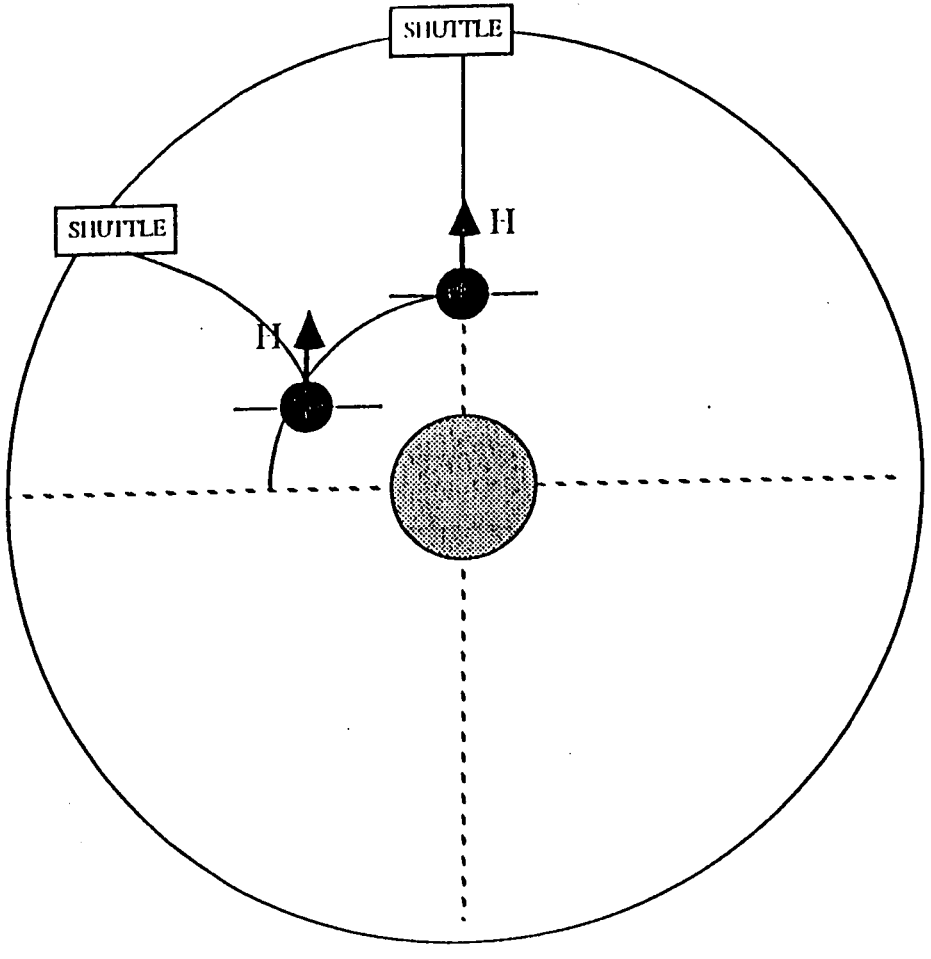
SPIN DYNAMIC STABILITY

October 12, 1987

- MOMENTUM VECTOR TENDS TO BE INERTIALLY FIXED
- TETHER TENSION MOVES AT ORBITAL RATE (4 deg/sec)
- COMPLEX MOTION OF SATELLITE LIKELY
- SHOULD/MUST BE EVALUATED BY SIMULATION

October 12, 1987

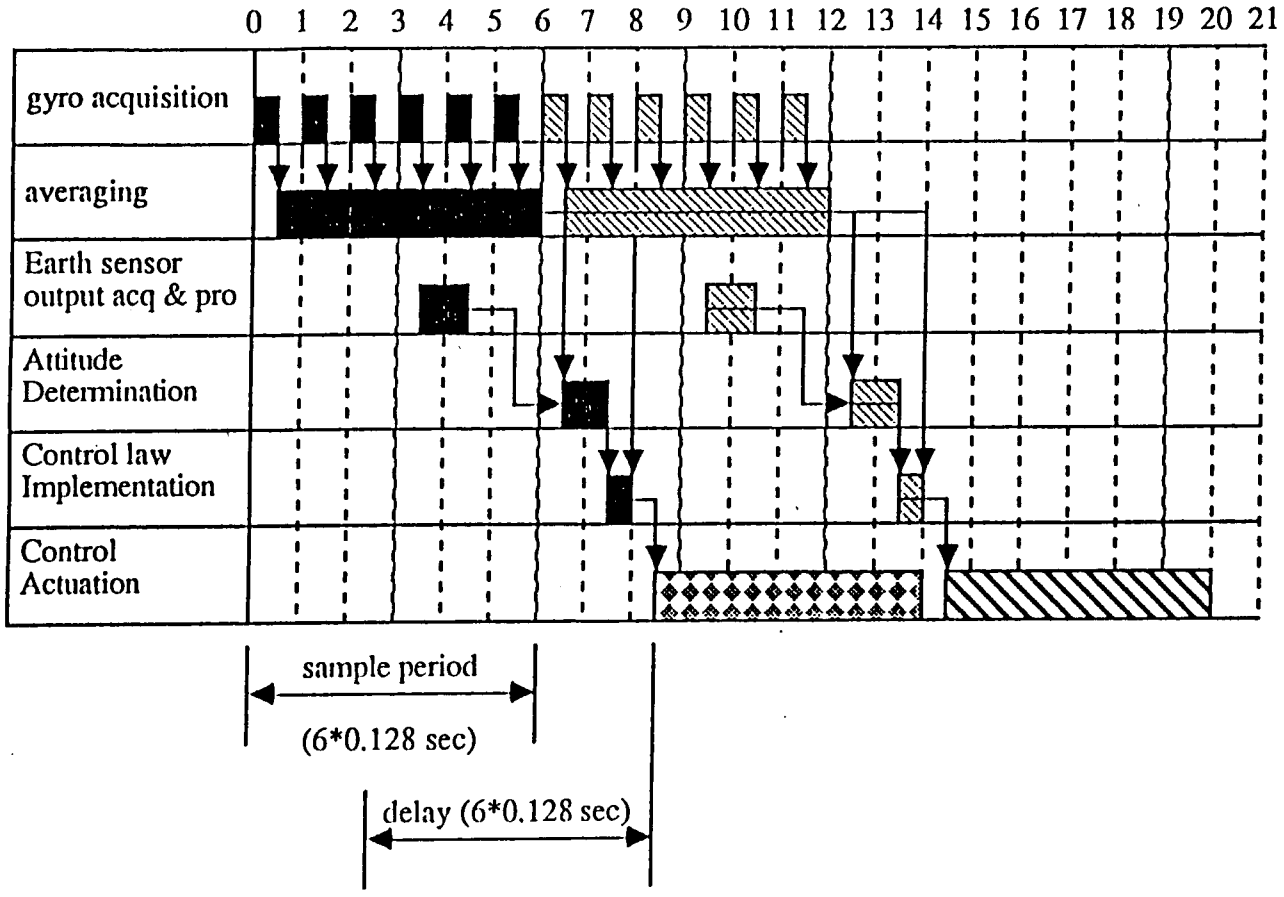
# ORBITAL DYNAMICS



SPIN CONTROL SYSTEM

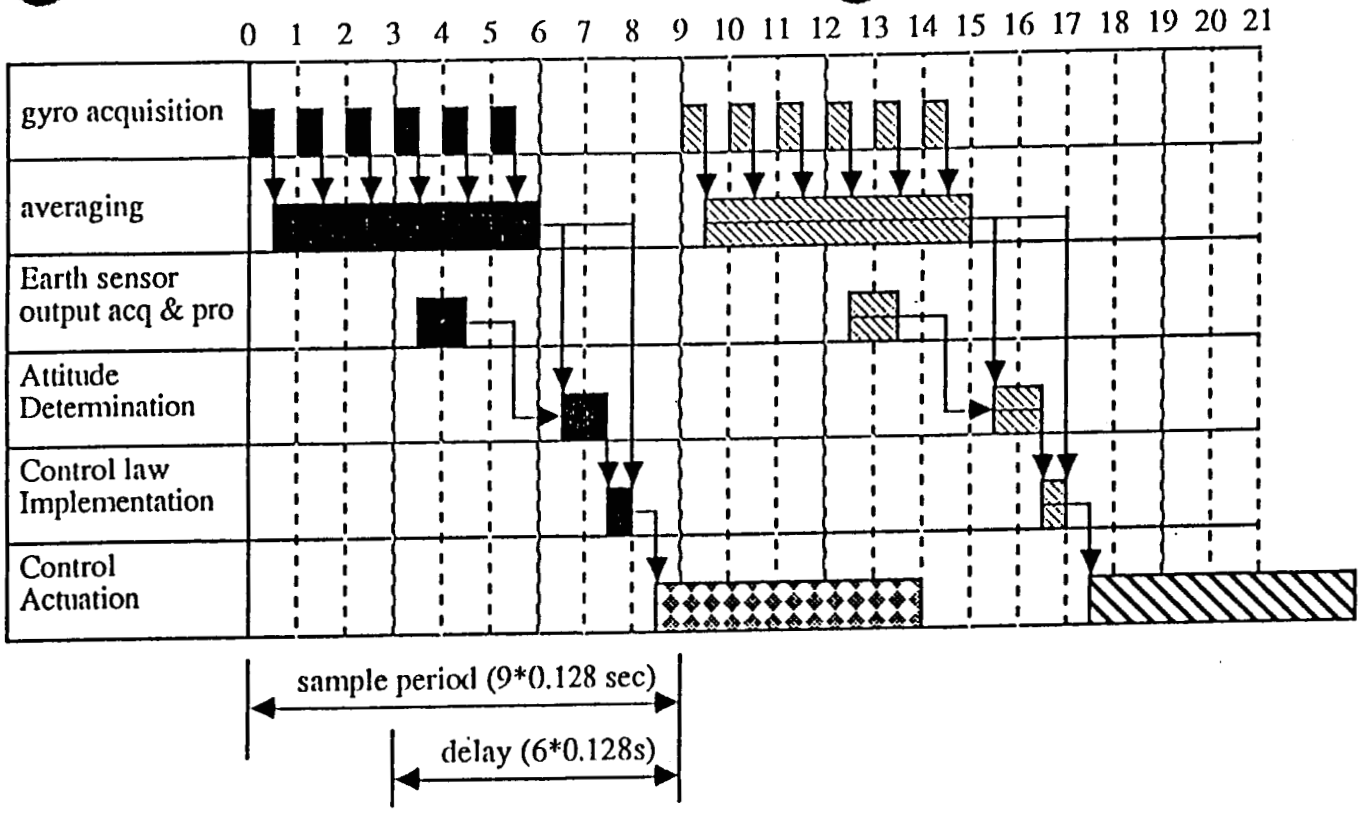
October 12, 1987

- SAMPLE RATE APPEARS TO BE 6 TO 9 CYCLES LONG
- CONTROL SYSTEM BANDWIDTH WILL BE LIMITED
- SAMPLE DATA STABILITY ANALYSES NEEDED
- 1 HZ BOOM EFFECTS SHOULD BE INCLUDED
- OUR QUESTIONS ADDRESSED THESE ISSUES



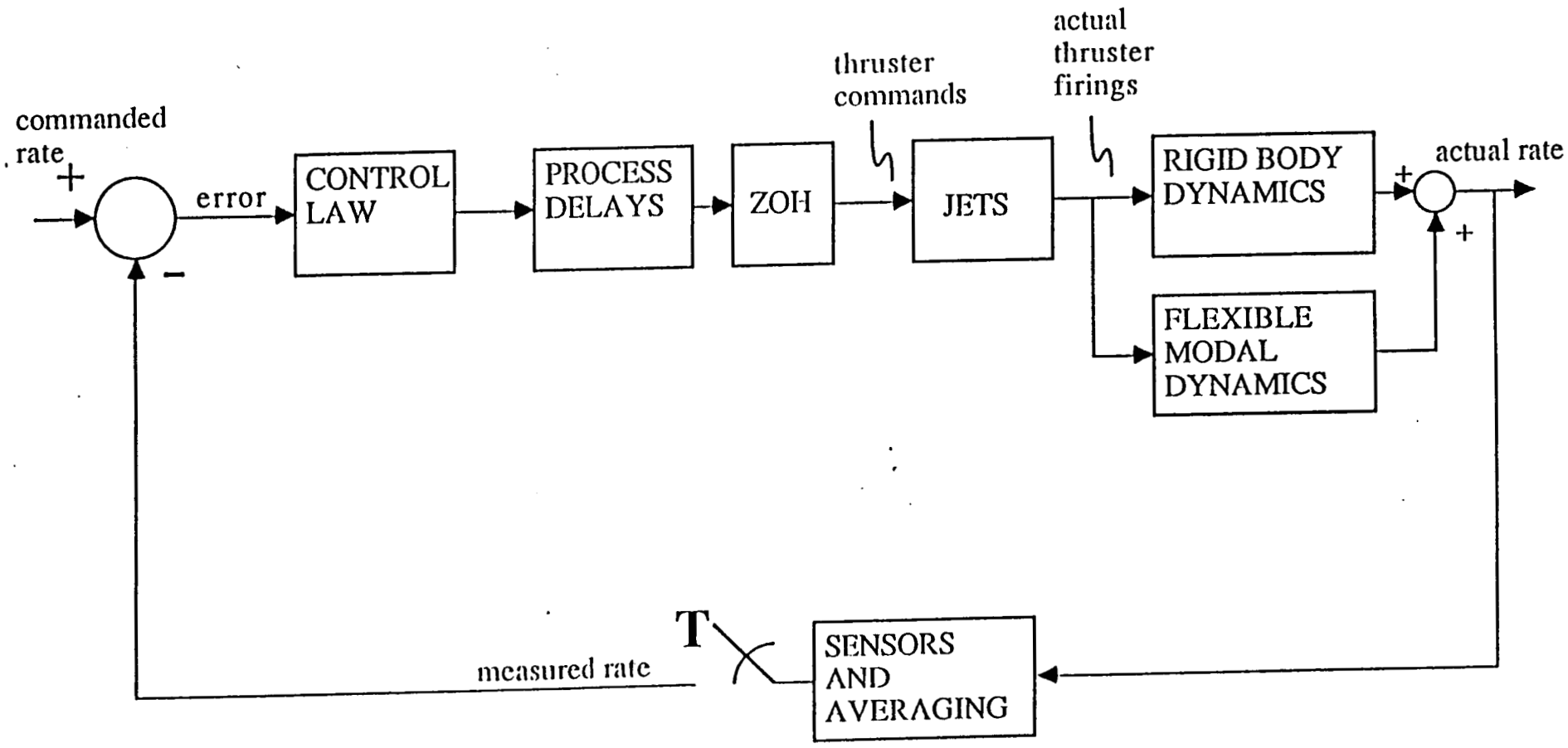

AERITALIA CONTROL LAW IMPLEMENTAION SCHEDULING

(OPTION # 1)

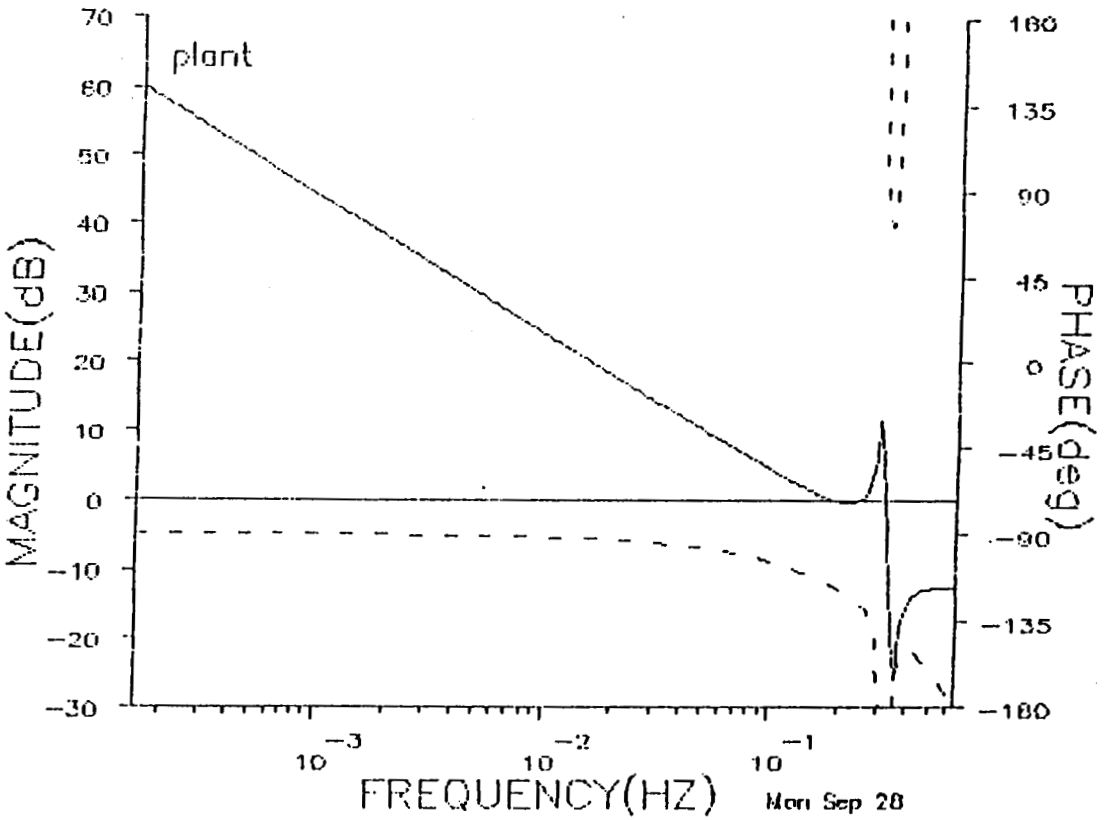



# AERITALIA CONTROL LAW IMPLEMENTAION SCHEDULING

(OPTION # 2)




# TSS CONTROL SYSTEM BLOCK DIAGRAM


plant
MAGNITUDE(dB)
PHASE(deg)
FREQUENCY(HZ)
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60
50
40
30
20
10
0
-10
-20
-30
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135
90
45
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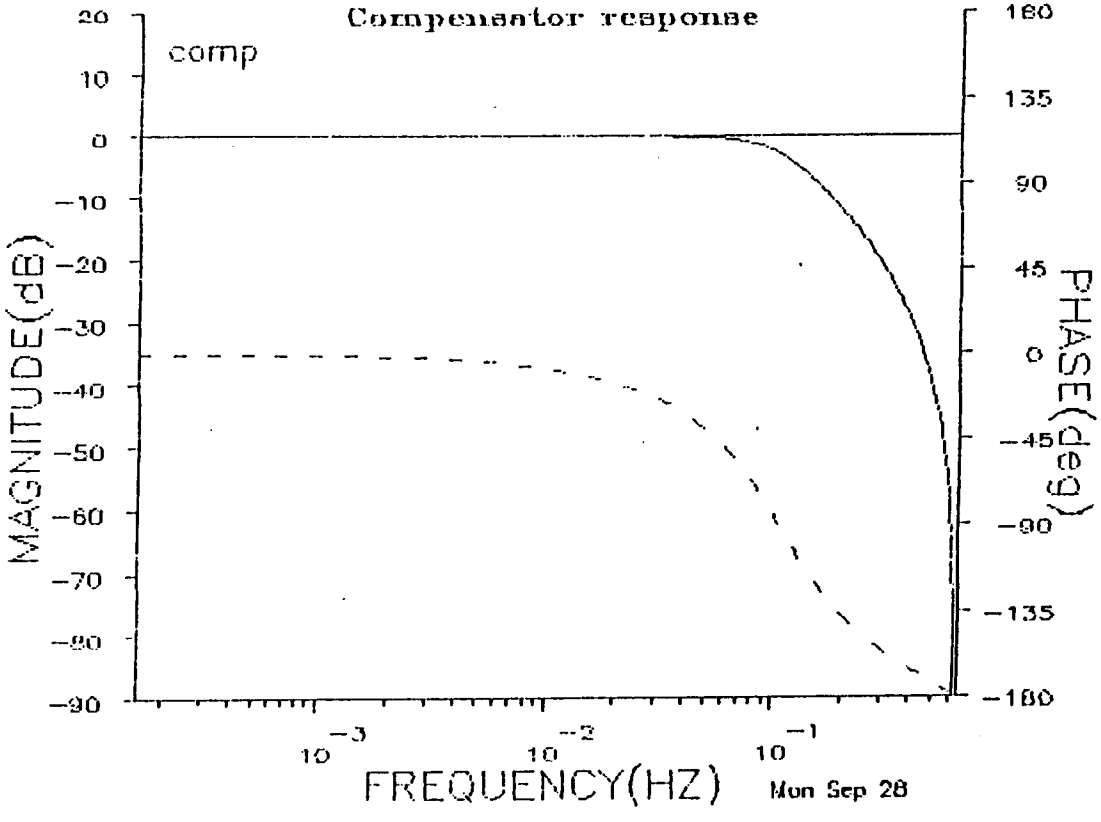
-90
-135
-180
10^-3
10^-2
10^-1
Mon Sep 28


Compensator response
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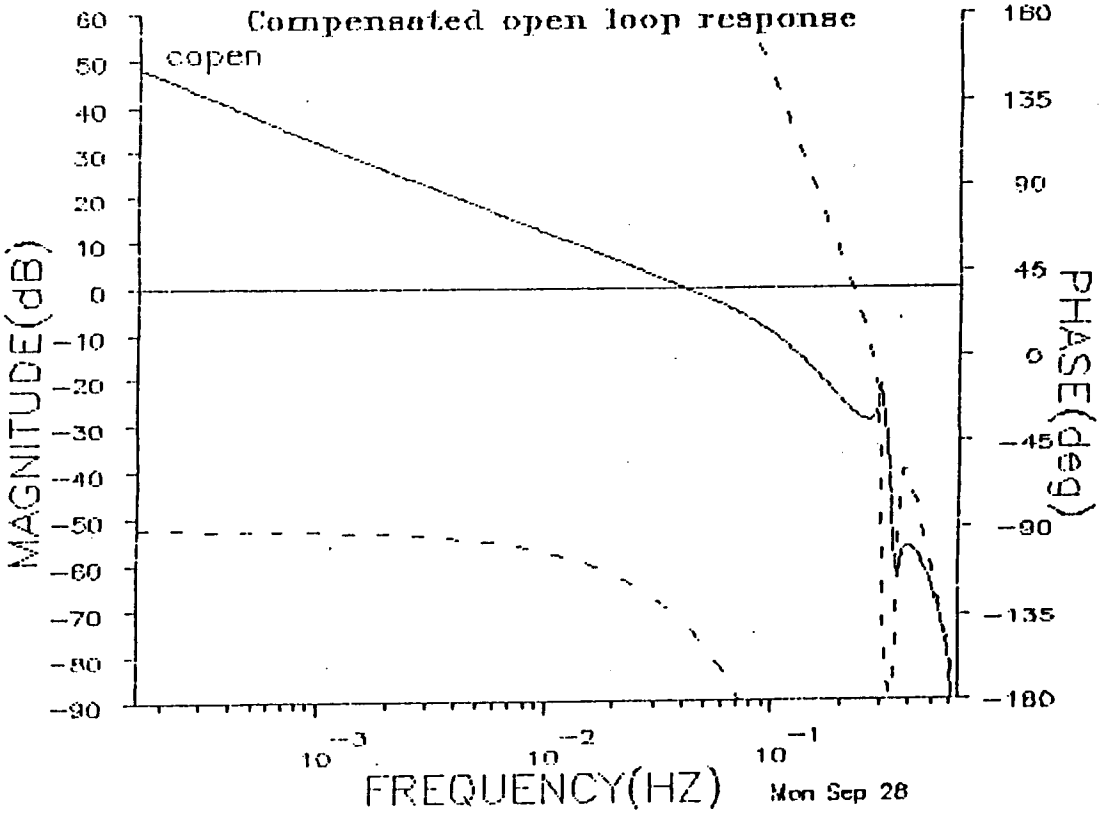
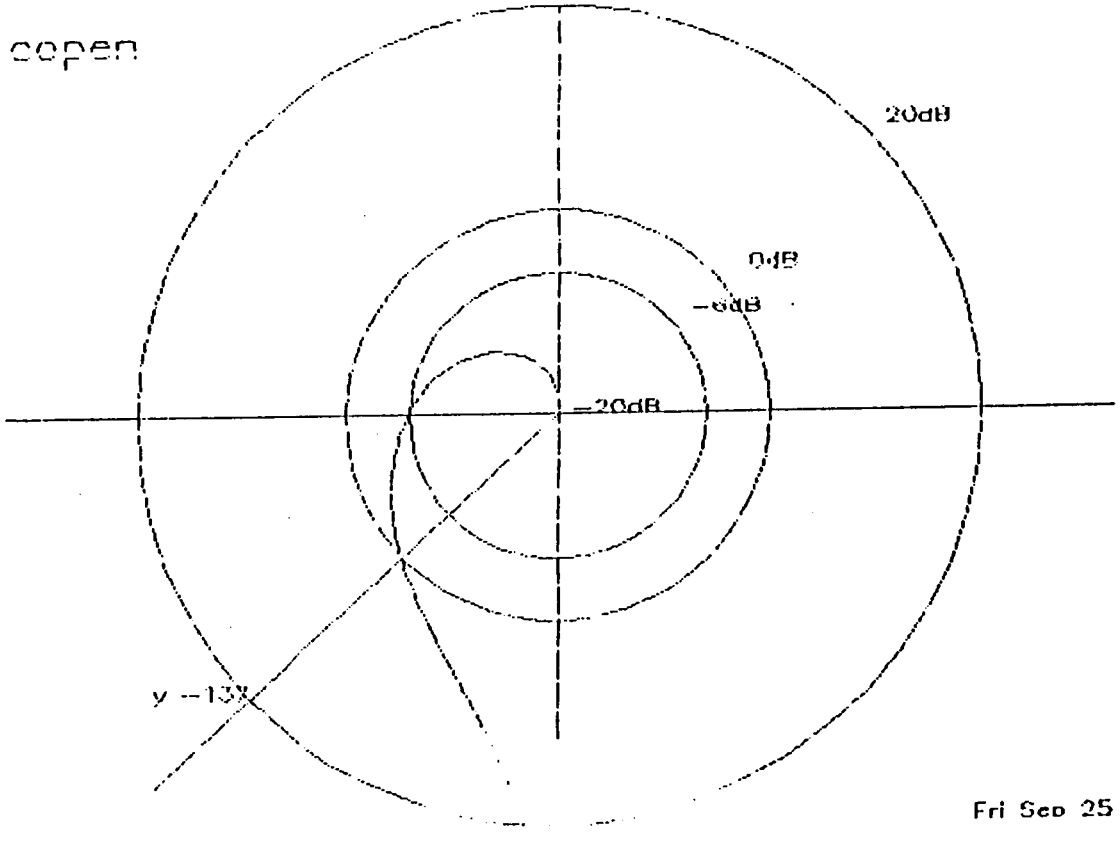
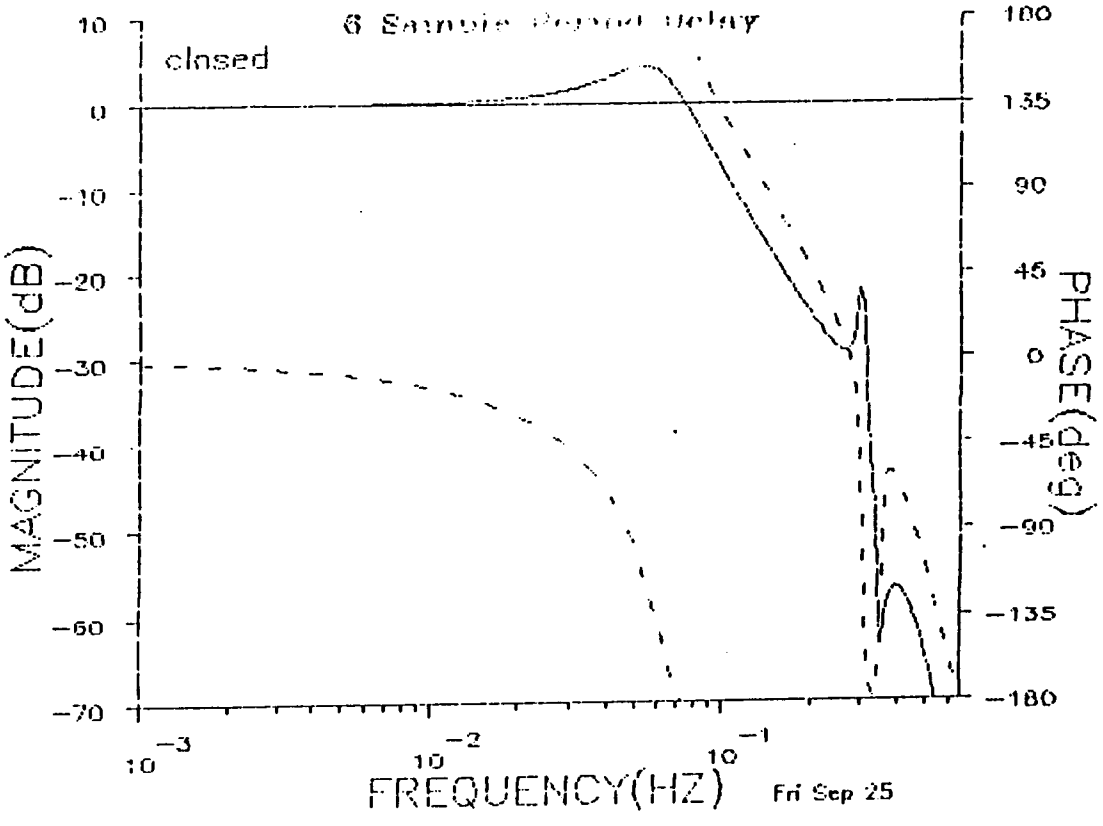
−10
−20
−30
−40
−50
−60
−70
−80
−90
MAGNITUDE(dB)
180
135
90
45
0
−45
−90
−135
−180
PHASE(deg)
10^−3
10^−2
10^−1
FREQUENCY(HZ)
Mon Sep 28

```
$

Fri Sep 25 16:04:19 CDT 1987

 COMPENSATOR TYPE: 2nd ORDER DIGITAL


 COMPENSATOR SPECIFICATIONS

 SAMPLING PERIOD=   .768000000000000
 PEAK FREQUENCY=   .666600000000000
 DAMPING COEFFICIENT (ZETA)=   .707000000000000

 GAIN FACTOR=  6.84950804826637E-002

 NUMERATOR COEFFICIENTS IN ASCENDING ORDER
 1.0
 2.0
 1.0

 DENOMINATOR COEFFICIENTS IN ASCENDING ORDER
 .698429154009129
 -1.863009839034673
 1.438561006956199
$
```


Compensated open loop response
copen
MAGNITUDE(dB)
PHASE(deg)
FREQUENCY(HZ)
Mon Sep 28
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
180
135
90
45
0
−45
−90
−135
−180
10^−3
10^−2
10^−1


copen
20dB
0dB
-6dB
-20dB
y -13°
Fri Sep 25


6 Sample Report delay
closed
10
0
-10
-20
-30
-40
-50
-60
-70
MAGNITUDE(dB)
100
135
90
45
0
-45
-90
-135
-180
PHASE(deg)
$10^{-3}$
$10^{-2}$
$10^{-1}$
FREQUENCY(HZ)
Fri Sep 25

SUMMARY

October 12, 1987

- ORDERLY PRESENTATION BY AERITALIA
- DESCRIPTION OF SATELLITE WELL UNDERSTOOD
- BOOM CHARACTERISTICS NEED TO BE CONTROLLED
- SAMPLED DATA CONTROL ANALYSES NEED TO BE PRESENTED

# APPENDIX K

# FINAL PRESENTATION AND RECOMMENDATIONS

# TETHERED SATELLITE SYSTEM (TSS)
# DYNAMICS AND CONTROL
# REVIEW PANEL

## PROGRESS REVIEW

NOV 23, 1987

# TETHERED SATELLITE SYSTEM (TSS) DYNAMICS AND CONTROL REVIEW PANEL

## AGENDA

INTRODUCTION

PANEL CHARTER/MEMBERSHIP

FINDINGS DEPLOYER

RECOMMENDATIONS DEPLOYER

FINDINGS SATELLITE

RECOMMENDATIONS SATELLITE

SUMMARY

2-2268-7-17

Marshall Space Flight Center

# Tethered Satellite System

## DYNAMICS AND CONTROL AND REVIEW PANEL

**Purpose:** Conduct a thorough and independent review of the performance, dynamics, control, and mission safety aspects of flying the TSS onboard the Shuttle in late 1990.

**Tasks:** Review/assess TSS dynamics and control work being performed by the prime contractor and other organizations supporting the TSS analysis effort.

Report on the adequacy and completeness of the present ongoing effort.

Report findings concerning the need for additional modeling, simulation, ground/space experimentation, and/or theoretical work in the field of dynamics and control.

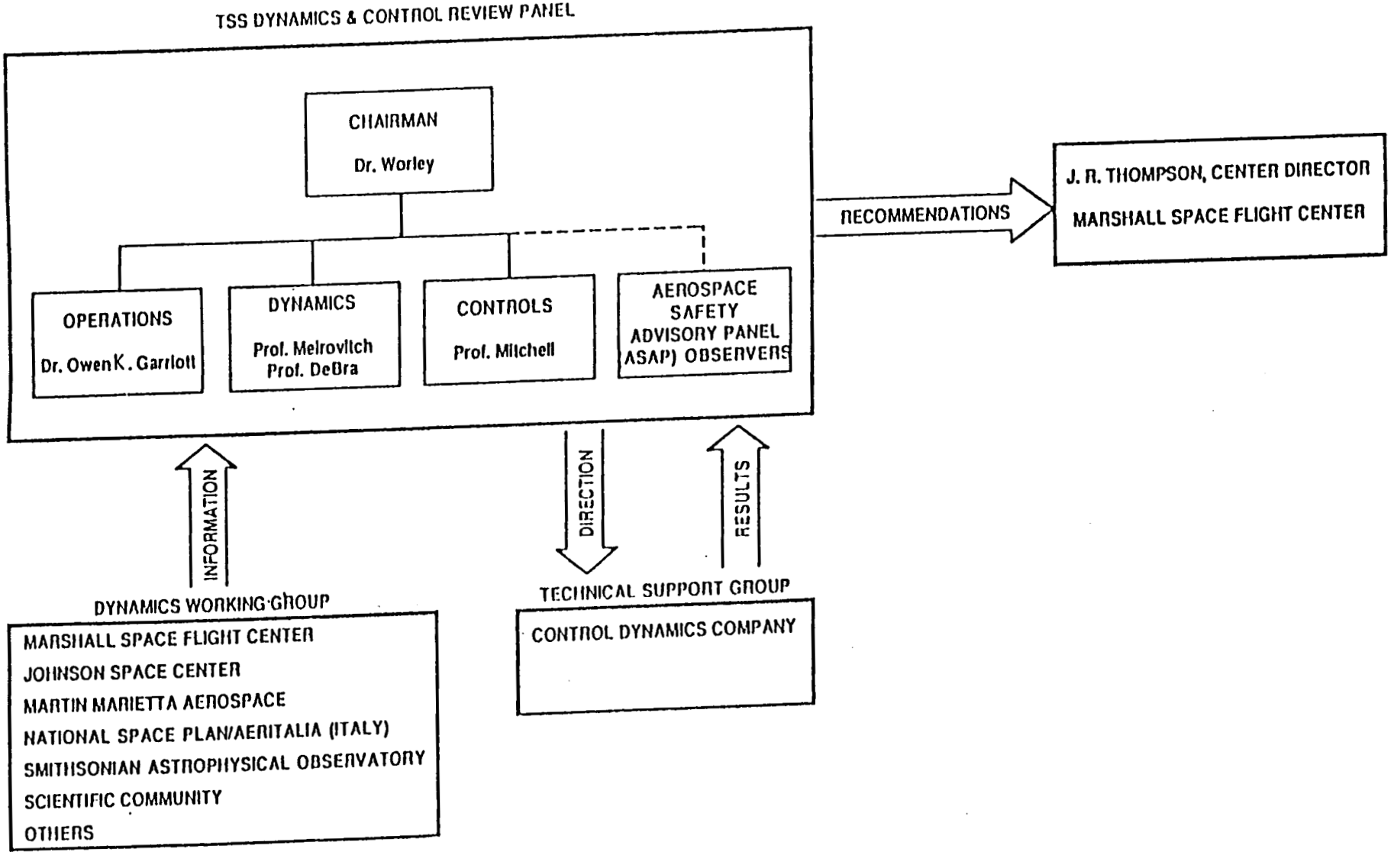
(Reference: Letters to panel members from James R. Thompson, Jr., dated March 2, 1987)

2-2240-7-17

Marshall Space Flight Center

# Tethered Satellite System

## TSS DYNAMICS & CONTROL REVIEW PANEL ORGANIZATION & DATA FLOW



## TETHERED SATELLITE SYSTEM (TSS) DYNAMICS AND CONTROL REVIEW PANEL

### FINDINGS - DEPLOYER

- DYNAMICS OF TETHERED SATELLITES IS WELL UNDERSTOOD.
  - DEPLOYMENT
  - ON-STATION

  } MINIMAL CONCERNS
  - RETRIEVAL ⇐ KEY DIFFICULTY
- SIMPLE CONTROL SCHEMES WILL SUFFICE TO BRING SATELLITE TO ORBITER VICINITY.
- BENIGN DYNAMICS MINIMIZE RISK TO ORBITER & CREW.
- THERE IS ACCEPTABLE RISK OF LOSS OF SATELLITE.
- PRIMARY RISK IS TO MEETING MISSION OBJECTIVES.

- IMPORTANT IMPROVEMENTS CAN/MUST BE MADE
  - GUIDANCE AND CONTROL SCHEME
  - ANALYSIS/SIMULATION/TESTING

# TETHERED SATELLITE SYSTEM (TSS) DYNAMICS AND CONTROL REVIEW PANEL

## PANEL RECOMMENDATIONS

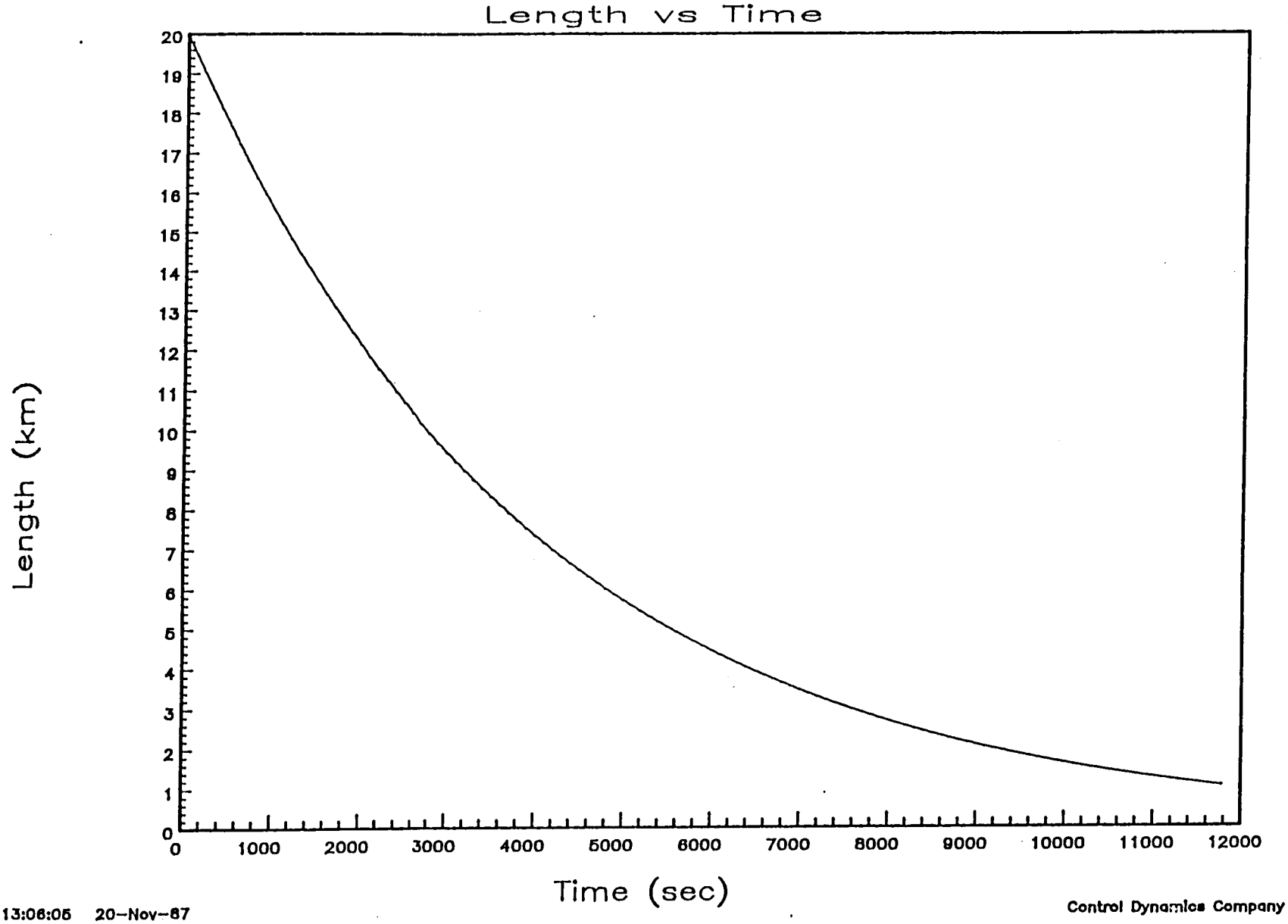
1. DEVELOP A SIMPLER GUIDANCE AND CONTROL CONCEPT WITH SUPPORTING PARAMETER STUDIES.

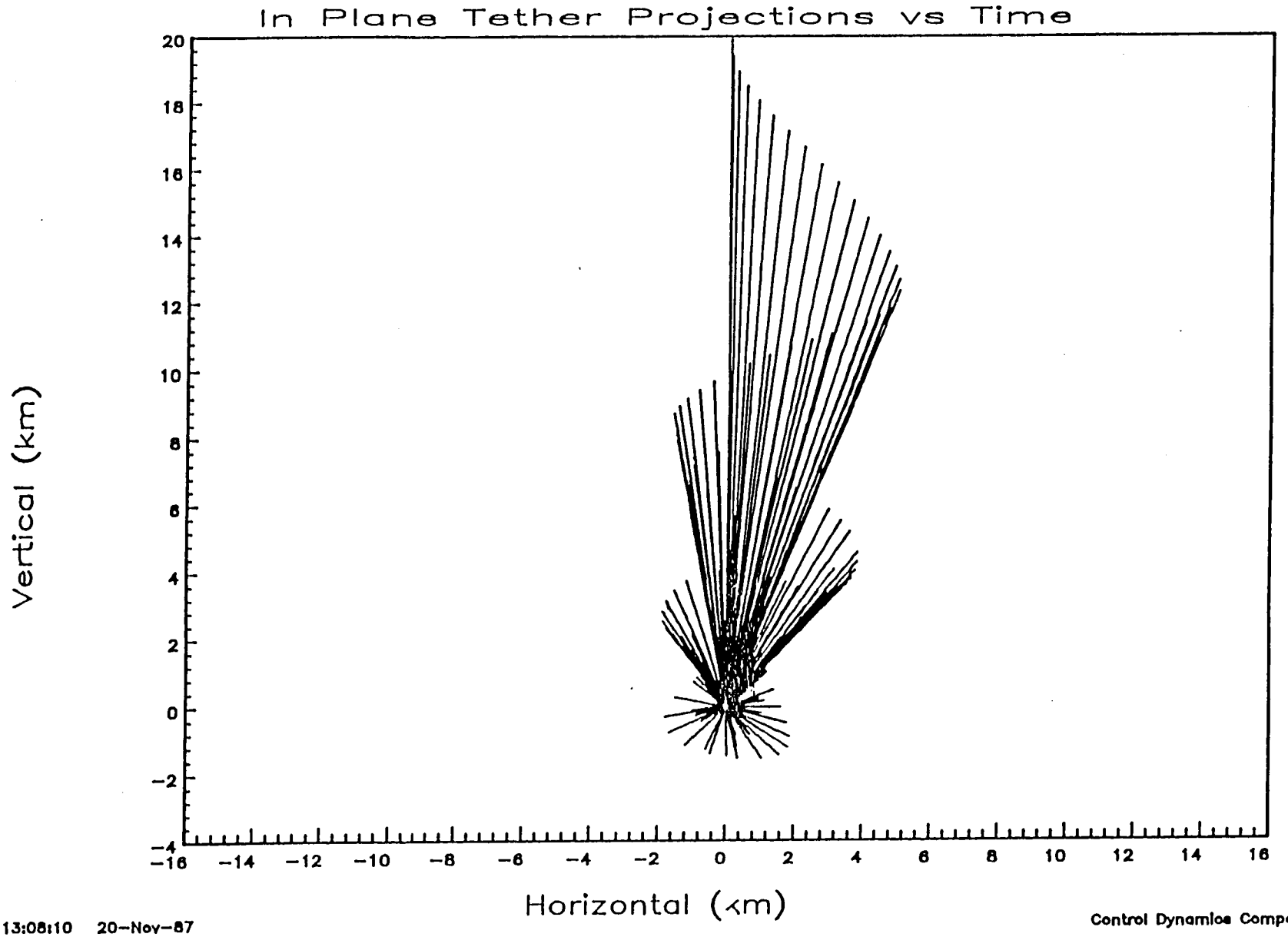
2. REVIEW THE COMPONENT AND SYSTEM TESTS IN GREATER DETAIL WITH EMPHASIS ON INTERRELATIONSHIPS AND REQUIREMENTS.

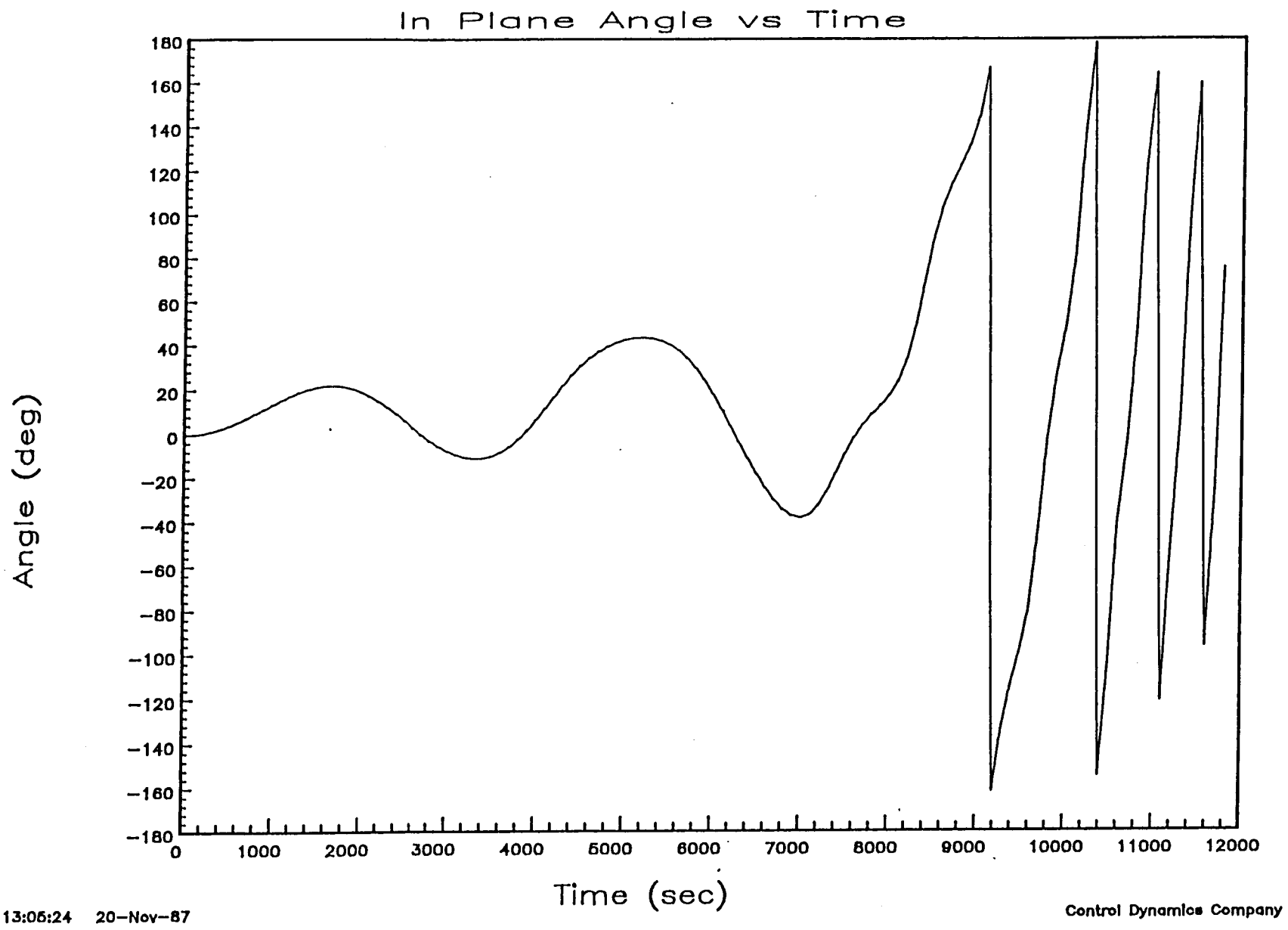
3. DEVELOP A DETAILED SIMULATION PLAN OUTLINING INTERRELATION BETWEEN VARIOUS SIMULATIONS IN GOVERNMENT AND THE CONTRACTORS.

4. FOCUS SAO ACTIVITIES ON TOUGH TECHICAL ISSUES WITH DEFINED OUTPUT (e.g. SLACK TETHER DYNAMICS).

5. INVESTIGATE PASSIVE RETRIEVAL WITH GREATER EMPHASIS.

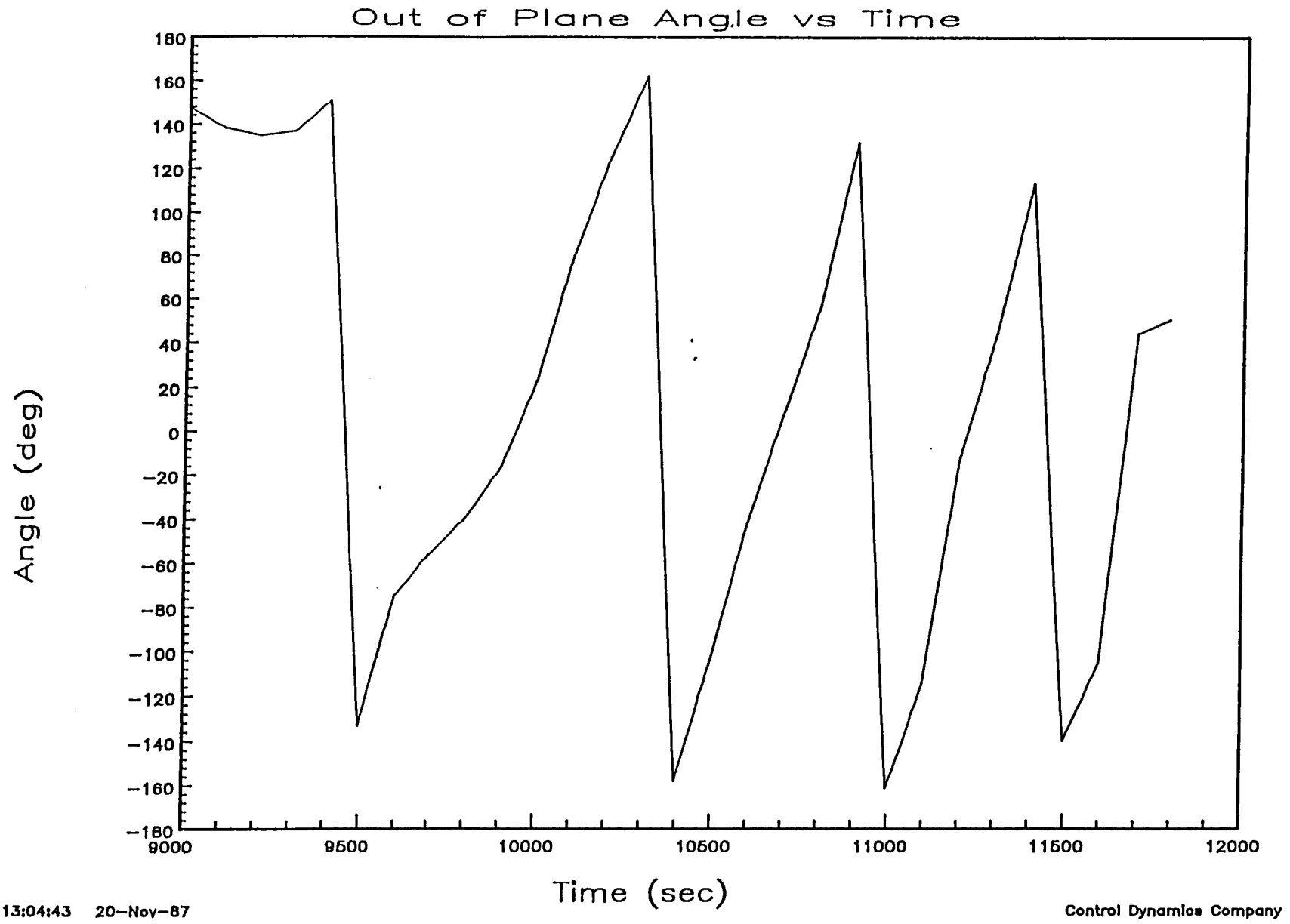

Length vs Time
Length (km)
Time (sec)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13:06:05 20-Nov-87
Control Dynamics Company


In Plane Tether Projections vs Time
Vertical (km)
20
18
16
14
12
10
8
6
4
2
0
−2
−4
−16
−14
−12
−10
−8
−6
−4
−2
0
2
4
6
8
10
12
14
16
Horizontal (km)
13:08:10 20-Nov-87
Control Dynamics Company




13:06:24 20-Nov-87

Control Dynamics Company


Out of Plane Angle vs Time
Angle (deg)
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
9000
9500
10000
10500
11000
11500
12000
Time (sec)
13:04:43 20-Nov-87
Control Dynamics Company

## FINDINGS - SATELLITE

- CONTROL DESIGN MEETS ALL REQUIREMENTS.
- CONTROL DESIGN VERIFIED BY DETAILED SIMULATIONS.
- IMPROVEMENTS CAN BE MADE TO INCREASE CAPABILITY.

## SATELLITE RECOMMENDATIONS

- CONTINUE TO MONITOR DESIGN PROCESS.
- CONSIDER ALTERING SAMPLING PROCESS TO GAIN PERFORMANCE IF/ONLY IF REQUIRED.

## TETHERED SATELLITE SYSTEM (TSS) DYNAMICS AND CONTROL REVIEW PANEL

### SUMMARY

- DYNAMICS WELL UNDERSTOOD AND RETRIEVAL CAN BE ACCOMPLISHED SAFELY.
- KEY ISSUES RELATE ONLY TO OPERATIONAL PERFORMANCE ISSUES.
- RETRIEVAL CONTROL DESIGN REQUIRES FURTHER WORK.
- PASSIVE RETRIEVAL SHOULD BE INVESTIGATED FURTHER.